

Investigating the prospects for Carbon Capture and Storage technology in India

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Executive Summary

The use of carbon capture and storage (CCS) technologies to mitigate the risk of climate change has received relatively little attention until recent years. They are, however, increasingly being proposed as potentially important contributors in global action on climate change. For example, the Stern Review notes that:

“[CCS] is a technology expected to deliver a significant portion of the emission reductions. The forecast growth in emissions from coal, especially in China and India, means CCS technology has particular importance.”

Chinese companies have recently started planning and constructing pilot scale (and larger) CCS schemes. The Indian Government and industry has, however, tended to take a more cautious approach. In this context, this study aims to examine whether CCS could be a suitable option for India and, if so, what role would be appropriate for various stakeholders, including developed countries, to play in its development within India. The primary research reported here is a survey-based exploration of stakeholder views on the suitability of CCS for India and how CCS could be developed and deployed.

There is a lively debate about whether CCS should be deployed in India. It is expected that coal will play a significant role in providing energy and electricity in India until 2050, at least, despite measures to significantly increase the role of other energy sources. Although CCS is not seen as an immediate priority for Indian Government or industry, survey respondents do expect it to become more important in the future, particularly for industry. Thus, it is appropriate to consider whether CCS is a technically feasible option for India and, if so, if and when it should be used.

Although there are some significant challenges, it seems likely that introducing CO₂ capture at Indian power plants could be technically feasible especially in locations where it is considered appropriate to apply ‘capture ready’ concepts for new build plants before CCS is deployed. Identifying both suitable storage sites and routes for transporting captured CO₂ safely to these sites also requires careful consideration. One important factor in shaping views on whether CCS is an appropriate option for India is the proposed timing of any deployment of possible projects. In particular, survey respondents typically suggest that it is necessary for developed countries to demonstrate CCS at commercial scale before any commercial-scale CCS projects in India are considered.

In fact, most survey respondents suggested that any consideration of deployment of CCS in India should be within an appropriate international framework, including measures for knowledge sharing and technology transfer that consider local conditions carefully. The importance of establishing reasonable methods to help with early engagement on CCS between India and developed countries was also noted by some respondents. For example, one respondent suggested that consideration should be given to establishing local knowledge/training centres within India. Survey respondents also suggested that it was reasonable for developed country governments to contribute to financing of both initial projects and wider deployment of CCS in India. This could partly be through international finance institutions such as the World Bank, the International Monetary Fund and the Asian Development Bank.

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1. Introduction

This report was commissioned by Christian Aid and written by researchers from the University of Edinburgh and the University of Surrey. It aims to explore the prospects for carbon capture and storage (CCS) to play a significant role within global action to mitigate the risk of climate change, with a focus on India. A short review of some actions recently undertaken and planned for CCS demonstration and deployment in China is also included. This illustrates some significant differences between these two important nations, even though some stakeholders do not always draw a clear distinction between them.

In recent years, there has been growing concern that anthropogenic emissions of carbon dioxide (CO₂) and other greenhouse gases could lead to dangerous climate change. One response to this has been the introduction of the United Nations Framework Convention on Climate Change (UNFCCC) which was agreed in Rio de Janeiro in June 1992. It entered into force in 1994 and aims to “achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system” (UNFCCC 1992). More recently the Kyoto Protocol to the UNFCCC has been the main international agreement for globally agreed action to mitigate the risk of dangerous climate change, as well as establishing appropriate options for adapting to impacts of climate change that are already occurring or are expected to occur.

In December 2009, parties to the UNFCCC will gather in Copenhagen aiming to agree actions to be taken in the future, particularly from 2012 to 2020. The UK Government has published its vision for a global deal at Copenhagen including the need for developed and developing countries to work together to mitigate the risk of dangerous climate change (DECC 2009a). Presently, developing countries are faced with a major dilemma: they have to cope with the adverse impacts of climate change and consider whether they should take action to mitigate the risk of more extreme impacts in the future while at the same time reducing poverty. For example, statistics from the International Energy Agency (IEA 2007) and the United Nations Development Programme (UNDP 2007/2008) indicate that there are still roughly 2.5 billion people who rely heavily on traditional cooking fuels, and around 1.6 billion who have no access to electricity in developing countries.

India is a developing country that illustrates the nature of this challenge. According to the International Energy Agency and United Nations Development Programme, it is home to more than a quarter of the world's poor and accounts for roughly 50% of energy impoverished people who have a high dependence on traditional cooking fuels, and for 31% of people without access to electricity (IEA 2007, UNDP 2007/2008). Economic development and the fulfilment of basic human needs such as education, sanitation, health and communication are critically dependent on the availability of modern energy services. For this reason, improved living standards in India are inherently linked with an increase in energy demand. This rise in energy demand has led to an increase in India's overall CO₂ emissions since the vast majority of the increase in energy demand has, so far, been met by

increased use of fossil fuels. Over 70% of India's carbon emissions are associated with the burning of fossil fuels, with a significant proportion of these associated with coal-fired power plants. In terms of electricity, India presently has roughly 138GW of installed capacity, where roughly 70% is generated by thermal power plants, 25% by hydro and 5% from other renewables, mostly wind (IEA 2007).

The IEA predicts that India will be in the top three emitters of the world by 2030 in terms of total CO₂ emitted each year and it is currently ranked sixth (IEA 2007). In terms of per capita emissions, however, India's were one sixteenth of the US and one third of China's in 2004 (IEA 2007). Since just over half of India's current CO₂ emissions are from large point sources (IEA 2007), it is important to consider whether such sources could be a suitable starting point for reducing CO₂ emissions by capturing, transporting and then storing CO₂ in porous rock as a mitigation strategy against dangerous climate change in CCS projects.

Although CCS technologies have received little attention until relatively recently, they have been identified as potentially important contributors to significantly mitigating the risk of dangerous climate change. For example, the Stern Review on the economics of climate change (Stern 2006) notes that:

"[CCS] is a technology expected to deliver a significant portion of the emission reductions. The forecast growth in emissions from coal, especially in China and India, means CCS technology has particular importance."

China is participating in a number of international collaborative projects on CCS, a Chinese company has constructed a pilot scale CO₂ capture unit and other, larger projects are being considered (see Appendix A). India has tended to take a more cautious approach and India's Government has indicated minimal interest in CCS demonstration or policy to date (section 3.3), particularly in comparison to China. A number of factors could explain this approach and are discussed in this report, including that initial findings seem to indicate limited geological storage capacity for CO₂ within India (section 3.1), although further characterisation of potential storage sites is required and it might also be appropriate to consider long distance transport of CO₂ to other regions.

Another important consideration for both India and China is whether appropriate mechanisms for knowledge sharing to allow lessons learned by initial commercial-scale demonstration and deployment of CCS (and other key technologies) in developed countries can be agreed. Concerns have been raised about the suitability of some financing mechanisms, e.g. the Clean Development Mechanism within the UNFCCC process (section 2.2). It is also necessary to ensure that local conditions affecting technologies choice for use in developing countries are taken into account within knowledge sharing frameworks. Given this context, and the different approaches to CCS observed in China and India in recent years, it is important to examine whether CCS could be a suitable option for India and, if so, what role would be appropriate for various stakeholders, including developed countries, to play in its development within India.

This report reviews some of the important considerations shaping Indian energy system decisions (section 2) and whether it is technically feasible for CCS to be implemented in India (section 3). The primary research carried out for this study is a survey-based exploration of stakeholder views on the suitability of CCS for India and how CCS could be developed and deployed in India, if it is deemed to be a suitable approach (section 4). The surveys were circulated and completed in May/June 2009. A wide range of stakeholders with different levels of experience and previous knowledge of energy and CCS in India were invited to participate. Eighteen stakeholders (out of a total of 65 contacted), predominantly from the energy sector, responded. Their affiliations ranged across academic institutions, private sector industry, Indian Government, and international financial institutions (see Appendix B).

2. Energy Security and Climate Change in India

Although the focus of this report is on whether CCS might have a role in India, it is first important to understand some key factors that are likely to shape decisions about the potential role for fossil fuels, and CCS used in conjunction with fossil fuels, within the Indian energy system. Two particularly important factors in the discourse around CCS in India are discussions on the appropriate response for India to make to the risk of dangerous climate change and a careful consideration of various aspects of energy security, including developing adequate supply to meet demand. Both of these factors are considered in this section.

2.1 Energy Security

‘Energy security’ can be used to refer to a broad range of issues including providing sufficient supply capacity to meet demand, security of reliable access to primary fuel to be used within a country and diversity of supply, which is sometimes seen as a proxy for security of access since it is assumed that multiple supply chains are less likely to fail simultaneously. Each definition of energy security brings with it a wide range of factors that must be carefully considered within energy system planning. The United Nations Development Programme (UNDP 2004) defined energy security as:

“...The availability of energy at all times in various forms, in sufficient quantities, and at affordable prices, without unacceptable or irreversible impact on the environment. These conditions must prevail over the long term if energy is to contribute to sustainable development. Energy security has both a producer and consumer side.”

Nevertheless, the term ‘energy security’ can have an even more complex meaning in the developing world context. Sethi (2009) argues that the increased use of commercial energy by those who currently use more than a ‘sufficient’ quantity simply because they can afford to do so, threatens the “very existence of those who never used it in the first place, or used it in insufficient quantities and at unreasonable prices.” Therefore, in the context of developing countries, such as India, ‘energy

security' may have strong overtones of equity and could imply a "moral responsibility towards reversing the historic impact on our global commons"¹ (Sethi 2009).

India is in a major predicament. The Government of India is committed to the Millennium Development Goals (MDGs)², which requires a significant increase in the proportion of the population with reliable access to energy. This will be a significant challenge since India has the world's largest concentration of poor people – over 830 million Indians live below \$2/day, where roughly 370 million of those live in abject poverty on less than \$1/day (UNDP 2007/2008). In terms of energy, over 600 million Indians live without electricity, and over 700 million still use traditional biomass as the primary fuel for cooking (IEA 2007). The responsibility for providing the energy for cooking through traditional biomass, notably, falls upon women and their daughters, who spend a total of 80 billion hours each year collecting firewood (Gibbs 2008). This dependence on biomass for cooking and heating causes more than 400,000 premature deaths (mostly women and children) in India annually, partly due to poor indoor air quality associated with traditional use of biomass (IEA 2007). A number of measures are planned including improving and expanding infrastructure for providing electricity.

India's efforts to alleviate poverty are, however, being undermined by vulnerability to climate change. A particular concern for India is that agriculture accounts for around one third of India's Gross National Product (GNP) and directly employs more than 60% of the Indian population (Gibbs 2008). Around 70% of India's population lives in rural areas and recent studies have shown that access to electricity is least among agricultural labourers (Gupta 2009). The Indian Government plans to invest heavily in the rural sectors, seeking to achieve more than 4% agricultural growth according to the draft paper for the 11th national plan, which will run from 2007 to 2012 (Gibbs 2008). The most recent review of the Intergovernmental Panel on Climate Change (IPCC) on likely impacts of dangerous climate change highlighted that India's agriculture and natural resources could be subject to extreme changes (IPCC 2007b). For example, Himalayan glaciers are amongst the fastest retreating in the world. Glacial meltwater is crucial to Indian agriculture since it feeds the major rivers on the sub-continent and accounts for 37% of India's irrigated land. It is possible that changes in this glacial meltwater will cause water shortages for 500 million people (IPCC 2007b).

A high proportion of India's energy comes from coal. To reduce dependence on coal and increase diversity, Indian policymakers are taking a growing interest in promoting energy efficiency and renewables. Although these measures can be expected to reduce emissions of greenhouse gases compared to use of fossil fuels for energy supply, a key driver for this alternative choice is to try to reduce security of

¹ The 'global commons' is anything that no single entity or person controls and that is central to life. It draws on the use of shared 'common' land for grazing animals, where it is likely that everyone will want more than their 'fair share' of the land and the commons are then likely to be damaged for all.

² United Nations' Millennium Development Goals represent a global partnership to achieve eight international development goals by 2015, including poverty alleviation, education, gender equality and fighting disease epidemics such as AIDS.

supply concerns related to the country's escalating fuel needs (TERI 2006). The Indian Government also sees a significant role for coal in the future, and as of February 2009³, has announced plans to invest in thirteen coal-fired Ultra-Mega Power Plants (UMPP)⁴. Of these, at least seven are planned under international bidding, and it is expected that these plants will come online beyond 2012 (Chikkatur and Sagar 2009).

2.2 Climate Change Strategy and International Engagement Activities

In response to the growing concern over the projected impacts of global warming on the Indian subcontinent, India's Prime Minister set up a council, consisting of ministers, bureaucrats, and experts from industry, academia and civil society, in 2007. Its role is to coordinate national strategies for adaptation and mitigation of climate change. India's first National Action Plan on Climate Change (NAPCC) was subsequently launched by the Indian Prime Minister, Dr. Manmohan Singh, on June 30th 2008. In this document the federal Government states that "the National Action Plan hinges on the development and use of new technologies", and lays out its strategy to combat climate change by means of eight "National Missions" (Gol 2008). The objectives of the missions focus on "promoting understanding of climate change, adaptation and mitigation, energy efficiency and natural resource conservation." The resources for these mission will be provided from the budgets of the remaining years of the 11th Five Year Plan (2007-2012) and through to the end of the 12th Five Year Plan (2013-2017).

Out of the eight, there are two missions that focus on energy – the National Solar Mission and the National Mission for Enhanced Energy Efficiency. It is in the latter that four new initiatives are proposed that are anticipated to "result in a saving of 10,000 MW by the end of the 11th Five Year Plan in 2012" (Gol 2008). One of these new measures includes mandating specific energy consumption decreases in large energy-consuming industries, with a system for companies to trade energy-savings certificates.

It is important to note that the NAPCC is not a legally binding document, but rather a statement of intent by the Indian Government. It is primarily based on the principle that maintaining high economic growth rates is essential for raising living standards of the vast majority, that essentially live below the poverty line. One result of improved living standards is expected to be that vulnerability to the impacts of climate change would be reduced. The NAPCC welcomes international cooperation, particularly from developed nations, for "research, development, sharing and transfer of technologies enabled by additional funding and a global IPR regime that facilitates technology transfer to developing countries under the UNFCCC" and also states that a "principle of equity" must underlie the global approach to combating climate change. Consequently, alongside demonstrating the willingness of India to play its part in mitigating the risk of global climate change, the NAPCC is also very clear in

³ See: <http://in.reidiff.com/money/2009/feb/02govt-may-limit-umpp-number-per-company.htm>

⁴ UMPP has a power generating capacity of 4GW per site. Thirteen UMPPs would mean 52,000MW of installed capacity.

asserting the position that most, if not all, developing countries hold when they come to the international negotiations:

“India is determined that its per capita greenhouse gas emissions will at no point exceed that of developed countries even as we pursue our development objectives.”

In terms of looking to the future, the NAPCC is not free from criticism, and has had a fair amount of disapproval in the Indian press, particularly due to an apparent lack of transparency of the process for developing the plans. The media has typically concluded that overall it will neither help the poor, nor the climate. For example, Sahgal (2008), India's leading environmental journalist, describes the NAPCC as “a tepid document that offered too little, too late,” arguing that it will have no impact because it “has been written by bureaucrats, not visionaries.” Particular concerns generally include that there was no mention of any plans to cut current subsidies for oil and coal, which are already creating distortions in the fuel supply and electricity markets. Others have highlighted contradictions including that the intention to maintain high growth rates will require India “to increase its power-generating capacity by more than 200,000 MW over the next decade and double that before 2026”. It has also been argued that the NAPCC falls short on how it plans to address growing demand for energy amidst the consequences of dangerous climate change and that if the current economic slowdown were to continue, “then funding for new investments in alternate energy and desire for technology transfer will remain squeezed” (Sharma 2008).

As well as developing its own national plan, India has been an active and regular participant in global negotiations on climate change under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC). It is a signatory to the UNFCCC and its Kyoto Protocol, although India currently has no greenhouse gas emission reduction targets under the Protocol since it is a developing country.

The general elections in India in early 2009 resulted in a stable government, under the leadership of re-elected Dr. Manmohan Singh, of the Indian National Congress led United Progressive Alliance (UPA). Jairam Ramesh is the newly appointed Minister of Environment and Forests, and he has already stated to the media that India is going to pursue, along with G77⁵ and China, an ambitious and equitable outcome at the multilateral UNFCCC negotiations in Copenhagen, in accordance with common but differentiated responsibilities and respective capabilities (Gol 2009). At the time of writing (July 2009), it is expected that India will reiterate its stand that the mandate of the Copenhagen negotiations in December 2009 should be to enhance long-term cooperation on climate change under the Bali Action Plan with sufficient finance and technology transfer from developed to developing countries. India has announced that during the Copenhagen negotiations

⁵ Group of 77 at the United Nations is a loose coalition of developing nations, designed to promote its members' collective economic interests and create an enhanced joint negotiating capacity in the UN.

it will push for a package that will focus global action primarily on adaptation, but also on carbon abatement and reduction (Gol 2009). It is anticipated that the NAPCC released in 2008 will continue to define the national strategy to tackle climate change.

One important mechanism within the Kyoto Protocol to the UNFCCC has been the Clean Development Mechanism (CDM). Under the CDM, it is possible for additional mitigation actions in developing countries to generate Certified Emissions Reductions (CERs) that can be bought by developed countries as an alternative to reducing their own greenhouse gas emissions. There has been some discussion about the potential for receipt of revenues from CERs under the CDM as a possible mechanism for financing CCS demonstration in India (Shackley and Verma 2008). However, inclusion of CCS under the CDM has been a contentious issue. A number of questions have been raised including whether CCS projects contribute to sustainable development and, for projects where injecting CO₂ into the subsurface results in enhanced hydrocarbon recovery, whether the whole project will lead to an overall reduction in CO₂ emissions (de Coninck 2008). Other concerns raised are that CCS may not be a mature enough technology to be considered for market-based deployment, and that the technology should be developed and tested in industrialised countries first, before it is considered for deployment in other countries (de Coninck 2008).

Even if CCS projects are accepted within the CDM, a number of factors are expected to affect whether CDM income would be sufficient to encourage CCS projects, including how quickly monitoring, reporting and verification (MRV) methodologies can be agreed and the time horizon over which support can be guaranteed. Discussions at the December 2008 UNFCCC Conference of the Parties (COP-14, Poznan, Poland) seem to indicate that the ongoing debate on the possible inclusion of CCS in CDM is unlikely to be able to provide short-term incentives for advancing CCS technology in developing countries (de Coninck et al. 2009). Furthermore, if CCS were to be successfully incorporated into the CDM framework, the projected price of carbon for CERs is currently too low to enable many, if any, CCS projects to proceed (de Coninck et al. 2009).

3. CCS feasibility for India

Jairam Ramesh, the Minister of Environment and Forests, has been quoted in media reports affirming that if India has to achieve 8-9% growth rate, then its energy consumption will increase by 6-7% annually. Despite action on energy efficiency and increasing use of renewable energy, it is expected that coal will be the main resource fuelling this increase in demand (TERI 2006). Considering this, he stated that India will “have to focus on clean coal technology, better investment decisions and environmental mitigation measures” (Dhar 2009).

‘Clean coal’ can cover a range of approaches including improving efficiency of electricity generation, reducing emissions of conventional pollutants (e.g. dust and oxides of sulphur and nitrogen) and co-firing biomass at coal-fired power plants to

reduce coal used per unit of electricity produced. Although a range of measures can be used for small to moderate reductions in emissions from coal-fired power plants, it is expected that options for carbon capture and storage (CCS) will be required if CO₂ emissions from fossil-fired power plants are to be reduced significantly to the levels that are expected to be required to mitigate the risk of dangerous climate change (Committee on Climate Change 2008).

The majority of this section will focus on whether CCS could be technically feasible in India. It will outline measures required for power plants to be able to capture CO₂ and the availability of suitable geological formations to store CO₂. Requirements for transporting CO₂ to storage sites are also considered. It is important to note that even if CCS is technically feasible, it may not be an appropriate technology for deployment in India for non-technical reasons. The question of whether CCS is appropriate for India is explored more thoroughly in the stakeholder survey reported in the next section, but a brief overview of recent and ongoing international engagement on CCS by the Government of India is included in this section.

3.1 India's Geological Storage Capacity

For CCS technology to be applicable it is, of course, necessary to identify suitable locations for safe, long-term storage of CO₂. The permanent storage of CO₂ is generally expected to involve the injection of CO₂ into suitable formations in large sedimentary basins⁶. Therefore, a detailed assessment of the storage potential, both in terms of quantity and integrity, is required for potential storage sites such as coal fields, oil and gas fields, and deep saline water-bearing reservoir rocks.

If suitable storage capacity is not available within a particular region, then ship transport of CO₂ to other regions with suitable capacity could be possible and is expected to be cost-competitive if long distance transport is required (IPCC 2005). For example, Kapila and Haszeldine (2009) discuss the option of exporting CO₂ for foreign EOR activities, most likely in the Middle East. Some of the UMPP projects are planned for coastal sites with large shipping terminals included as an integral part of the project for coal import. It may be possible for tankers that currently deliver gas (in the form of LPG) to India from countries such as Qatar to be converted to take return loads of CO₂ for injection into depleted gas or heavy oil fields.

The focus of this review is, however, on whether there are suitable geological formations available for CO₂ storage in the Indian subcontinent. At present, there is limited knowledge in this field due to a general dearth of essential data required to characterise geological sites. Nevertheless, preliminary studies indicate that potential storage sites on the subcontinent are located in the Gangetic (north, northeast), Brahmaputra (northeast, Bangladesh border) and Indus (northwest, Pakistan border) river plains, and along the immediate offshore regions on the Arabian Sea (southwest coast) and Bay of Bengal (southeast coast) (IPCC 2005). Locations of

⁶ Basins in this context are structural formation of rock strata, depressions, and usually of considerable size.

these sites in relation to some of India's largest industrial point sources of carbon dioxide emissions are illustrated in Figure 1.

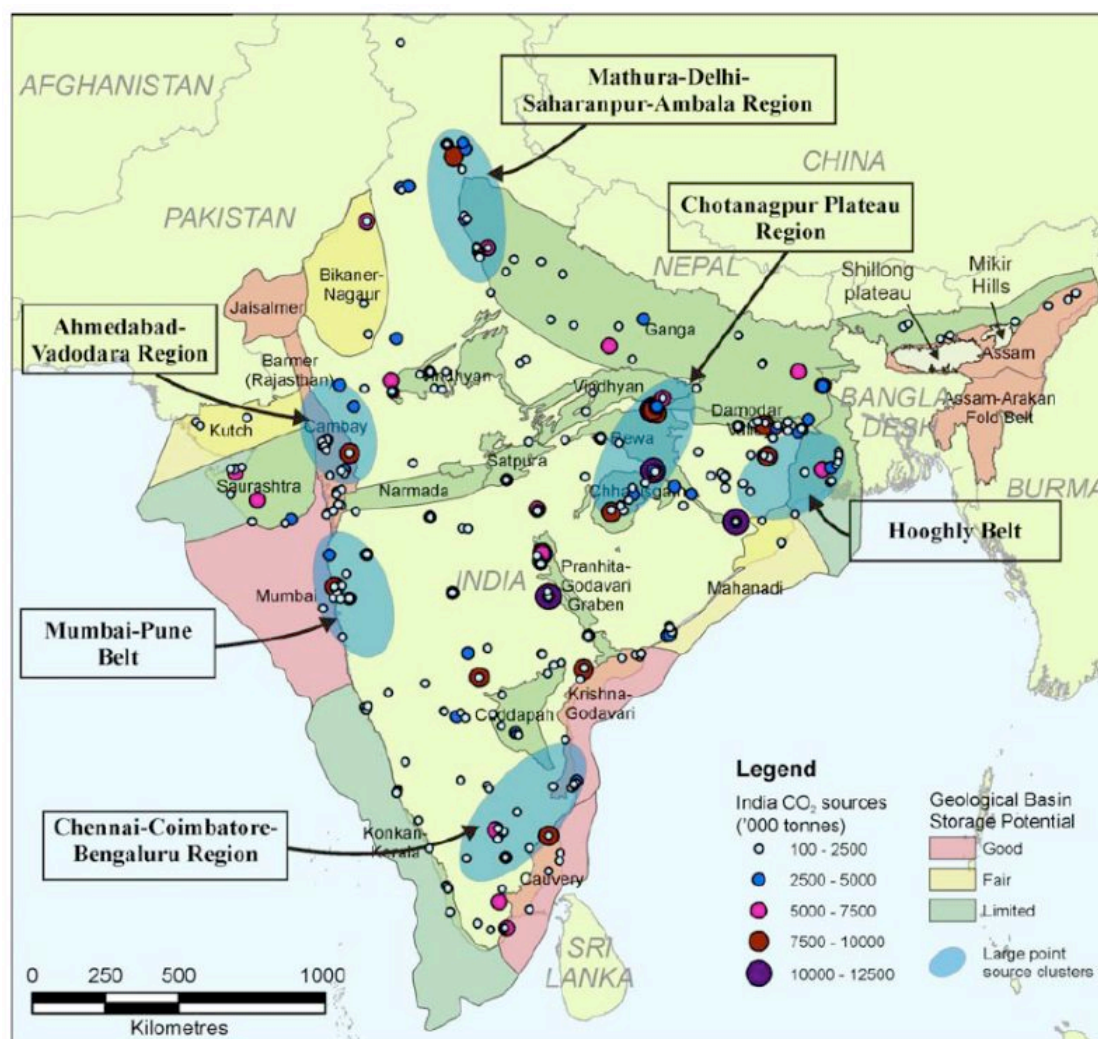


Figure 1 India's main industrial clusters and its geological basins with storage potential (source: IEAGHG 2008).

Initial attempts at evaluating the storage potential in India were made by Singh (2006), estimating that roughly 5 Gt CO₂ could be stored in unmineable coal seams, 7 Gt CO₂ in depleted oil and gas reservoirs, 360 Gt CO₂ in offshore and onshore deep saline aquifers, and 200 Gt CO₂ via mineralization in basalt rocks. The latter estimate refers to laboratory experiments conducted by McGrail et al. (2006) that demonstrated a relatively rapid chemical reaction of CO₂-saturated pore water with basalts to form stable carbonate minerals. This presents quite an appealing opportunity for India as a very extensive portion of the central peninsula consists of one of the worlds largest basalt lava flows known as the Deccan trap formation. As a result, there is continued collaborative research taking place in this area between India's National Geophysical Research Institute (NGRI) and the USA's Pacific Northwest National Laboratory (PNNL), under the auspices of the Carbon Sequestration Leadership Forum. However, this concept is still in the experimental

phase and can only be considered a possibility if the basalt is adequately permeable to the CO₂ and can be demonstrated to be safe (Schaef et al. 2009).

A recent study conducted for the IEA Greenhouse Gas R&D Programme (IEA GHG 2008) by the British Geological Survey has revised down the estimates that were first made by Singh et al. in 2006. The authors still conclude that there may be significant CO₂ storage potential “in the oil and gas-bearing sedimentary basins around the margins of the peninsula, especially in the offshore basins, but also onshore in the states of Gujarat and Rajasthan” (IEAGHG 2008, p. 2). It should be noted, however, that these potential storage sites are not well placed in respect to major CO₂ sources occurring in the central parts of the peninsula, as illustrated in Figure 2.

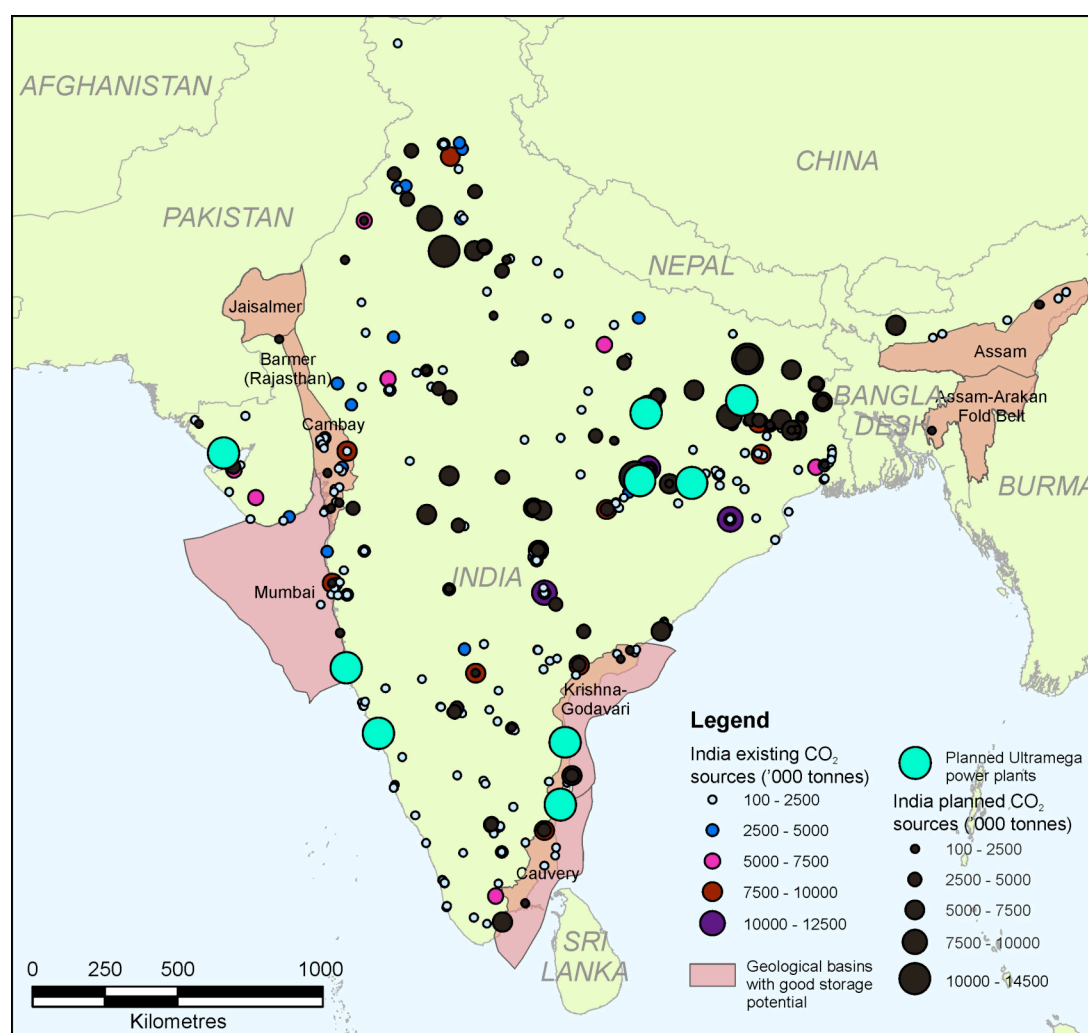


Figure 2 India's planned and existing CO₂ sources in 2008, and geological basins with good storage potential (source: IEAGHG 2008).

This 2008 BGS assessment of potential for geological storage in India suggests that CO₂ storage in coal seams is likely to be constrained since these coal reserves can be easily mined and used as fuel (IEAGHG 2008). Taking this into consideration, the calculated storage potential countrywide was found to be more of

the order of 345 Mt CO₂ in the major coalfields, where none have the capacity to store more than 100 Mt CO₂, and only eight of the fields can store more than 10 Mt CO₂ (IEAGHG 2008). For oil and gas reservoirs, the authors calculated the total storage capacity to be between 3.7 and 4.6 Gt CO₂. Furthermore, the authors noted that only a few fields, such as the Bombay High field and offshore Mumbai, are thought to have ample storage for the lifetime emissions of a medium sized coal-fired power plant, although it is technically feasible for one capture plant to use multiple storage sites during its lifetime. None of the fields, it would seem, are large enough to store the lifetime emissions of India's planned UMPPs (currently estimated each to produce 28-29 Mt CO₂/year for a period of 35 years, or roughly 1 Gt CO₂ in total for each UMPP).

Some areas in the northeast, such as Assam, are thought to have reasonable CO₂ storage potential, although this region is quite distant from the main emission sources, requiring thousands of kilometres of pipeline infrastructure, typically costed at \$1M per km. In addition, the most direct pipeline route passes through Bangladesh and significant increases in pipeline length would be required to avoid crossing Bangladesh. It should also be noted that even though the Indo-Gangetic plain, that lies in China, Nepal, India and Bangladesh, with the largest portion in India, has significant technical potential for storage, it has been classed as 'limited' by the authors of IEAGHG (2008), so is not shown on Figure 2. This is due to public acceptance concerns over possible conflict between multiple uses of land since this area is drained by several rivers and is, therefore, an extremely fertile region with over 580,000 square km of arable land that supports a population close to half a billion. This region represents India's agricultural heartland, and it is considered to be one of the "bread-baskets" that feed the world (UNDP 2007/2008).

Overall, although there are concerns that there will be limited storage capacity compared to the volumes of CO₂ that could be captured if CCS is deployed in India, it is likely that some CO₂ could be stored in the subcontinent. As in other locations, both the greatest potential capacity and most uncertainty is associated with CO₂ storage in deep saline aquifers. Current estimates could be improved with the aid of oil and gas exploration data, such as seismic and well-log data. Basalts could also provide significant storage capacity in India, but further research is required in this area. Although it has not been discussed in detail within this report, the implications of seismic activity in parts of India also need to be taken into consideration for any assessment of storage capacity and options for ship transport of CO₂ captured in India to other regions could also be explored.

3.2 CO₂ capture options and the potential role of capture readiness

A number of options are available to capture CO₂ from power plants and other large point sources of CO₂. In 2005, the Intergovernmental Panel on Climate Change published a special report on CCS (IPCC 2005) which outlined technologies that are relatively close to commercial deployment, as well as a range of options that are less well-developed but may provide promising alternatives in the future. Although the details of most, if not all, options have progressed since 2005, the basic principles have not changed so the IPCC special report still provides a useful introduction.

Three approaches to CO₂ capture from coal-fired power plants are generally viewed as closest to commercial deployment: post-combustion capture, pre-combustion capture and oxyfuel combustion (see Figure 3). There is currently no clear ‘winner’ between these technology options and variations in site-specific factors are likely to determine which option will be best for a particular site. Table 1, from Chalmers et al. (2007), gives an overview of some factors that need to be taken into account for coal-fired power plants. Similar considerations are also relevant for other use of fossil fuels including natural gas-fired power generation and coal use for industrial processes (e.g. steel production). Site specific factors must be considered for both base power plant choice (e.g. pulverised coal combustion or gasification of coal) and CO₂ capture approach used. Although some work may be required to adapt particular CO₂ capture technologies to Indian coals and operating conditions, it is likely that differences in base power plant choice will be a more important factor in determining which CO₂ capture technologies are likely to be suitable for deployment in India.

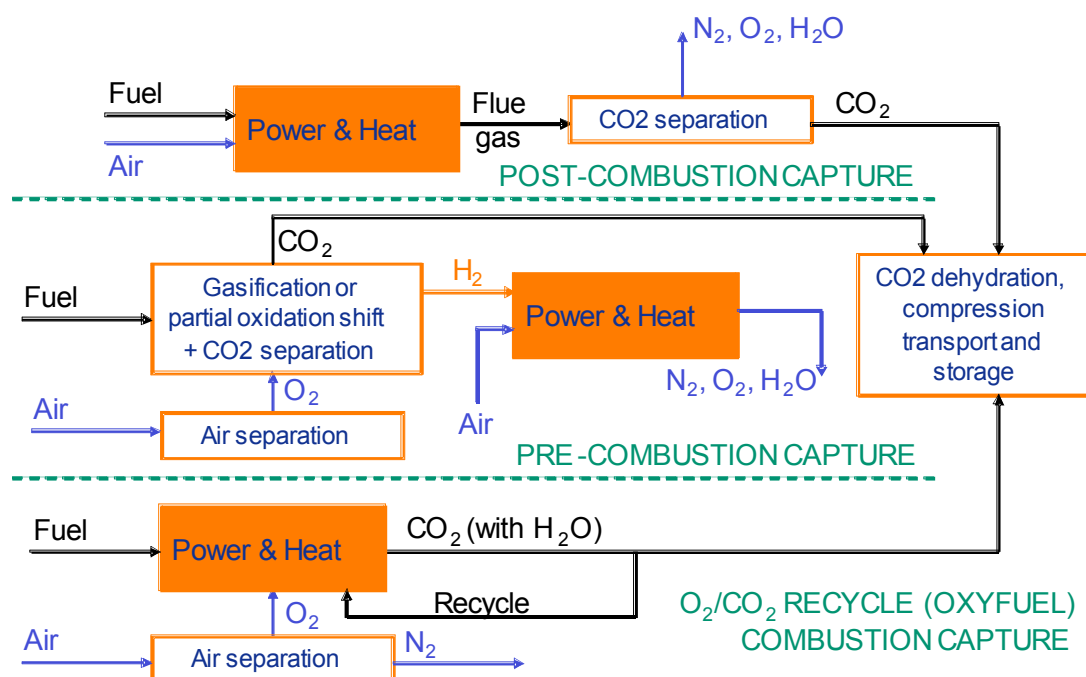


Figure 3 Schematic diagram of CO₂ capture technologies closest to commercial deployment for coal-fired power plants (after Jordal et al. 2004)

Table 1 Summary of some key considerations for determining power plant cost and technology choice (from Chalmers et al. 2007)

	Factors that can restrict options available (regardless of how much an investor could pay) as well as changing cost	Factors that change cost of electricity sold but that are unlikely to lead to a particular plant design option being technically impossible
Coal-fired power plant with no carbon capture considerations	<ul style="list-style-type: none"> • Type of coal available • Water availability • Availability of raw materials for any required pollution control measures • Planning (and other) regulations • Lack of infrastructure (and not able to build it) 	<ul style="list-style-type: none"> • Labour availability/cost • Cost of commodities and components (for construction and operation) • Financial factors, including tax regime and interest rates • Ambient conditions, particularly temperatures • Policy factors, including support mechanisms
Coal-fired power plant with carbon capture considerations (including capture-ready)	<ul style="list-style-type: none"> • Access to viable route to transport CO₂ to safe geological storage • Availability of additional raw materials for CO₂ capture • For capture-ready design, space/ access for retrofitting capture 	<ul style="list-style-type: none"> • As above, but costs likely to have different sensitivity to external changes – e.g. since wider range of commodities and components to construct and run, and different project risk leading to different financial structure

The current fossil-fired fleet in India is dominated by coal-fired power plants with sub-critical steam conditions. The composition of typical Indian coals mean that modifications to standard plant designs used in other parts of the world are required, due to a number of factors including high ash content. Many plants are 500MW units with assisted circulation boilers (Chikkatur and Sagar 2009). More recently supercritical plants which heat steam to higher temperatures and, hence, are more efficient have started to be introduced in India. Chikkatur and Sagar (2009) report that supercritical technology is “well-suited” to Indian conditions, partly since a number of plants have been built worldwide and the technology can be considered proven. It is expected, however, that coal washing⁷ may be increasingly important to minimise the risks of boiler tube damage associated with burning typical Indian coals. There are also concerns that it may not be technically feasible to move to advanced supercritical steam conditions, which would allow higher plant efficiencies to be obtained, with Indian coals even with coal washing (Chikkatur and Sagar 2009).

In 2008, a study on the risks of moving to more advanced steam conditions for the UMPP projects that are being commissioned by the Indian Government was undertaken by Mott MacDonald, with funding from the UK Foreign and Commonwealth Office, partly in response to comments made at an earlier stakeholder workshop in India (Mott MacDonald 2008a). In addition to considering

⁷ Coal washing removes ash and impurities from coal, leading to improved combustion and, therefore, higher power plant thermal efficiency.

the impact of Indian coals, the study considered other factors including “Indian environmental conditions, a limited local manufacturing capability and a lack of technology deployment experience”. The three main categories of risks identified by the risk analysis undertaken by Mott MacDonald were plant performance under Indian conditions, economic viability of advanced technologies and the level of support that the potential value of Certified Emissions Reductions (CERs) that might be available within the Clean Development Mechanism (CDM – see section 2.2 for further details). The techno-economic modelling carried out, informed by the risk analysis, concluded that:

“there are small differences between all technology options with low supercritical appearing the most attractive investment at all CER values for Indian coal and up to around US\$20 per CER for plants firing international coal. However, the differences between cases are small and considered to fall within the accuracy band of the modelling.”

In parallel to the work on moving to advanced steam conditions for pulverised coal plants, Mott MacDonald also completed a study exploring the potential for making UMPP projects ‘CO₂ capture-ready’ (Mott MacDonald 2008b). The Mott MacDonald study used an approach to making new plant capture ready originally proposed by IEAGHG (2007), and that is expected to be adopted as the basis for UK capture ready regulations (DECC 2009b). This involves a comprehensive but flexible set of assessments of a new plant design to ensure that avoidable barriers to the retrofit of CCS are minimised. Almost all of the modifications identified in the IEA GHG Carbon Capture Ready (CCR) method can be summarised as identifying and leaving ‘intelligent space’.

Based on this approach, plant capital requirements are reported to be increased by no more than 1% for the essential design changes required for a typical UMPP to be capture-ready. Under the CO₂ price scenarios assumed, it is also suggested that capture-readiness “would be a commercially attractive proposition” since it is valuable for plants to have the option to retrofit CO₂ capture at minimal, although still significant, cost in the future.

One of the most controversial aspects of developing capture-ready projects can be in determining what measures should be required to show that any CO₂ captured at a particular site will be able to access a suitable storage site. Within the Mott MacDonald study, it is assumed that:

“Preliminary confirmation of feasible routes to CO₂ storage should be undertaken, with the planning horizon and any required regulatory changes, to overcome current barriers, understood prior to generation plant construction.”

At the time of the study, nine UMPP sites had been identified: three coastal sites using international coals and six inland sites using Indian coal and located at the pit-head. It was concluded that CO₂ capture could be economically viable for all

sites under the CO₂ price scenarios considered, although expected costs could be around \$5/tCO₂ higher for the inland sites when compared to coastal sites, mostly due to increased transport distances for CO₂ storage. It is also important to note that successful deployment of CCS projects in any jurisdiction will require that adequate project finance can be obtained. Making the case for project finance requires a number of factors in addition to cost to be taken into account. For example, uncertainty associated with any incentives for reducing CO₂ emissions are likely to lead to project financiers requiring that CO₂ prices are higher than implied by only cost considerations for CCS projects to proceed, at least in the short to medium term.

As discussed above (section 3.1), further work is required to produce more robust estimates of the location and likely capacity of Indian storage capacity. It is also possible that ship transport of CO₂ to other regions could be a cost-competitive option for some projects, if CCS is implemented in India. As illustrated in Figure 2, in section 3.1, there is also some clustering of major CO₂ sources (including major industrial sites as well as power plants) in India, including where a number of power plants are located close to coal reserves. The UK and Europe have been considering the potential to take advantage of such clusters to minimise CO₂ transport costs by using a shared infrastructure for long distance pipelines (e.g. Element Energy et al. 2007). This approach could also be considered if CCS is deployed in India.

It is, of course, also important to consider whether existing plants could be retrofitted if CCS is deployed in India, even if they were not built capture-ready. The suitability of existing plants for CO₂ capture retrofit will depend on a number of factors including site-specific considerations such as space available for construction and ease of access to make modifications to the base power plant for integration between the power plant and the capture plant. Although much of the literature in the first few years of the 21st century tended to suggest that retrofits would not be economically feasible (IPCC 2005), more recent studies indicate that retrofits to existing plants could be worthwhile from a financial perspective, as long as they are technically feasible. For example, Simbeck and Roekpooritat (2009) review the potential value of retrofitting CCS within the existing US fleet and conclude that “most existing coal power plant sites are likely too valuable to ever abandon due to location, existing permits and infrastructure”. One concern raised about CO₂ retrofits is that the energy requirements associated with a CO₂ capture process will reduce plant capacity unless additional fuel is used (or a major upgrade to improve base plant efficiency is carried out). It is important to note, however, that if an existing plant continues to run, even at a reduced capacity, this avoids the need to build some replacement capacity if the alternative would have been to shut the entire plant down. This situation could occur if, for example, costs associated with CO₂ emissions rise due to global (or local, in some jurisdictions) policies to reduce greenhouse gas emissions.

Finally, another option that is considered for new-build coal-fired power plants in some jurisdictions is integrated gasification combined cycle (IGCC) technology. As suggested by the name, IGCC plants gasify coal instead of combusting it. The syngas (a mixture of carbon monoxide and hydrogen) produced by gasification is

then burned in a combined cycle plant. When CO₂ is captured at an IGCC plant, the carbon monoxide is converted to CO₂ plus more hydrogen, typically using a water-gas shift reaction. The CO₂ is then separated from the hydrogen to be transported to safe storage and the hydrogen is used in a combined cycle power plant (or can be diverted to some other use).

There has been very limited global deployment of IGCC to date (July 2009), partly due to the relatively high costs of IGCC compared to pulverised coal plants when CO₂ capture is not required. Initial studies of the economics of power generation with CO₂ capture have suggested that the costs of producing electricity from coal with CO₂ capture could be similar for IGCC and state-of-the-art pulverised coal-fired power plants with CO₂ capture (e.g. Davison 2007). It is likely, therefore, that different technologies will be better suited to particular sites depending on a number of local factors. For example, Chikkatur and Sagar (2009) note that many Indian coals cannot use the most common gasification process (slagging entrained-flow) due to high ash content and high ash fusion temperatures. Therefore it is likely that Indian coals will favour the continued use of pulverised coal power plants for providing electricity from coal, even if CO₂ capture is used. Although other gasification options with greater circulation of solids may be appropriate, they are not yet considered commercial. Circulating fluidised bed boilers (sometimes known as CFBC – CFB combustion) may also be used for Indian coals and could be adapted to include CO₂ capture, if appropriate.

In summary, an IPCC special report on CCS published in 2005 identified a number of CO₂ capture options that are relatively close to commercial-scale deployment at power plants. Although commercial-scale demonstration of these options is required before they are considered proven for widespread use, they are typically based on processes that are well understood in other applications. An important consideration for current power plant construction activity is, therefore, whether plants should be made 'capture-ready'. A study of possible technical and economic performance of UMPP projects by Mott MacDonald, funded by the UK Foreign and Commonwealth Office, concluded that the essential requirements for capture-readiness should cost no more than 1% of the total capital required for these projects.

It is generally important to consider whether changes to international 'standard' designs are required for Indian coals for both base power plants and CO₂ capture equipment. The discussion in this section has focussed on base power plant choices since it seems likely that these will be more important than variations in CO₂ capture technology in determining which approaches are most suitable for Indian coals and operating conditions. In particular, with current technology it seems likely that options that continue to use pulverised coal (rather than gasifying coal) could be preferred in India. Although it is expected that retrofitting CO₂ capture will be easiest at plants that have been built capture-ready, recent work has also suggested retrofits to other existing plants could be economically viable at sites where it is technically feasible to install CO₂ capture and for which a suitable route to a storage site can be identified.

3.3 Indian Government engagement on CCS

As already noted, the viability of CCS as an option for mitigating the risk of dangerous climate change depends on a range of non-technical factors, in addition to consideration of technical viability. A number of these factors are discussed with the stakeholder survey results presented in the next section. One important consideration is whether CCS can be politically acceptable and this section, therefore, reviews recent and current (July 2009) engagement on CCS by the Indian Government.

The Government of India is currently taking part in international initiatives, including the Carbon Sequestration Leadership Forum (CSLF), which was founded by the US in 2003. By 2006 India had signed a pact with the US on the FutureGen project and made a contribution of USD 10 million. As already noted, the CSLF endorses research in India that focuses on the storage potential of basalt formations, which underlie much of the subcontinent. In addition, since the role of CCS in developing countries featured in the G8 Communiqué from Gleneagles in 2005, the Indian Government has been engaging in discussion with European governments, and in particular with the UK. The Indian Government has also hosted a series of international workshops on CCS and R&D challenges, starting with two held at the National Geophysical Research Institute, Hyderabad in 2006 and 2007. In January 2008, a joint workshop between the UK Department of Environment, Food and Rural Affairs (DEFRA) and the Indian Department of Science and Technology (DST) was held to look at the prospects of CCS technology in India. An outcome of this international dialogue has been the establishment of the Indian CO₂ Sequestration Applied Research (ICOSAR) network by the DST.

Despite Indian interest in CCS research, a number of studies have indicated that the Indian government shows minimal interest in CCS demonstration or policy (Narain 2007; Shackley and Verma 2008; Kapila and Haszeldine 2009). Viewpoints collated from industry and government in these previous studies indicate that CCS is considered a “frontier technology” that needs to be developed further in developed countries first to bring down the cost through R&D and deployment (Shackley and Verma 2008).

Nonetheless, the Indian Government has started considering certain CCS projects for potential applications for support under the Clean Development Mechanism (CDM). For example, it is possible to use captured CO₂ for Enhanced Oil Recovery (EOR) and one proposal suggests the use of CO₂ from an offshore sour gas facility at Hazira, Gujarat for EOR at an onshore site 70 km away. An estimated 1200 tonnes of captured CO₂ would be transported to this oil field on a daily basis (0.36 Mt CO₂ /yr) and be used to maintain pressure in the field, rather than decrease the viscosity of the oil remaining in the field⁸ (Shackley and Verma 2008; Kapila and Haszeldine 2009). This would result in a large percentage of the captured CO₂ remaining in the pore space and not returning to the atmosphere.

⁸ There are different approaches available to enhanced oil recovery. When CO₂ is used as a miscible gas to reduce viscosity much of it is produced with the additional oil so it must be re-injected for permanent storage.

As in other jurisdictions, some stakeholders argue that the ability to improve oil recovery can significantly improve project economics making a useful contribution to early deployment of CCS. Increased hydrocarbon production could also be seen as important for other reasons, including reducing the proportion of Indian primary energy supply that must be imported. The storage assessment undertaken for the IEAGHG (2008) discussed above (section 3.1) indicates that there is potential for CO₂ storage in the offshore basins around Gujarat, such as the Cambay, which are in close proximity to the Hazira industrial belt that lies within the Ahmedabad-Vadodara region (Figure 1). An early project in this region could, therefore, be useful to provide information about the subsurface geology in this area that could facilitate more rapid development of further projects. There has, however, been some contention around whether CCS projects should be allowed in CDM, as mentioned previously (de Coninck 2008). It is also important to consider whether additional oil produced in EOR projects would have been produced by other means if CO₂ had not been injected when determining the net CO₂ emissions reduction credited to an EOR project (de Coninck et al. 2009).

4. Survey Methodology and Results

The primary research results are reported in this section and are based on a survey carried out in May/June 2009. It was designed to explore stakeholder views on the suitability of CCS for India and how CCS could be developed and deployed in India, if it is deemed to be appropriate for the Indian context. A wide range of stakeholders with different levels of experience and previous knowledge of energy and CCS in India were invited to complete the survey, which contained three sections, and was composed of seventeen questions in total. A list of participants' organisations is included in Appendix B and the survey itself is included as Appendix C to this report.

4.1 Overview of survey structure and respondents

The survey was a combination of multiple-choice, ranking and open-ended questions, all of them giving participants the opportunity to express their expert opinion. The first section consisted of nine questions. They intended to explore opinions on the importance of climate change and energy security for India and also asked for views on how energy and electricity supply in India might develop between now and 2050. The second section of the survey contained five questions that explored viewpoints on whether CCS might have a role to play in India's energy landscape. This included questions considering more detailed issues around how CCS technology could be deployed, if it was decided that it was a suitable technology to be used in the Indian context. Section three of the survey was primarily aimed at gathering information about the respondents in terms of profession and focus area of work. This was to allow analysis of any significant differences between perspectives of different stakeholder groups who had participated in the survey.

The survey was sent out to sixty-five individuals based in a wide range of stakeholder organisations in India, UK and the US. Regardless of the country they were based in, all individuals invited to participate were either working on, or had previously worked on, issues related to energy and India. The same proportion of tier 1⁹ and tier 2¹⁰ stakeholders were asked to participate in the research, with backgrounds ranging across academic institutions, private sector industry, Indian government, and international financial institutions. In all, eighteen stakeholders, predominantly tier 1 and from the energy field, participated in this research. The professions of respondents were fairly consistent regardless of the sector (e.g. industry, academic etc) they worked in and were primarily researchers, policy analysts, technical experts, and business planners as illustrated in Figure 4.

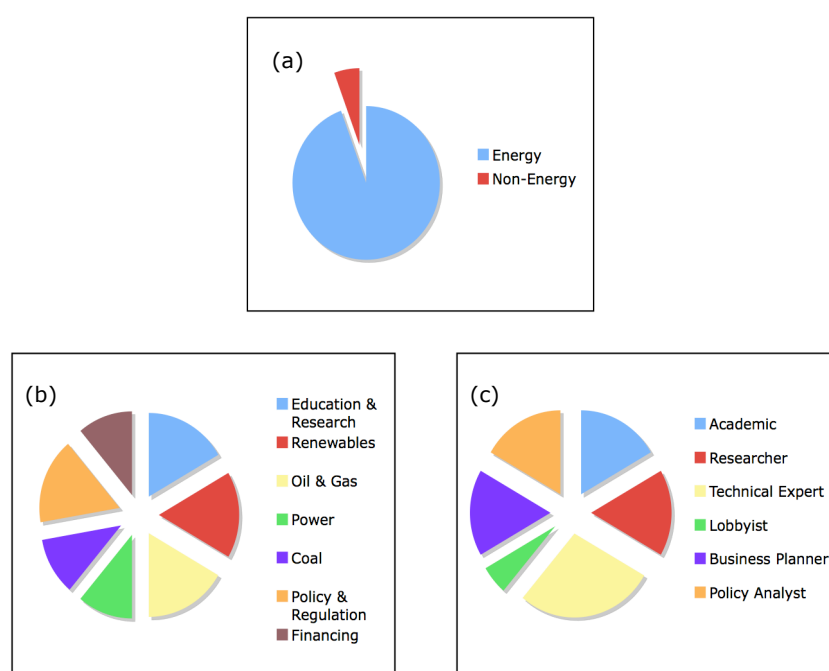


Figure 4 Background of survey participants in regards to (a) whether they work directly in the energy field, (b) the main focus of their work in the energy field, and (c) their profession.

The remainder of this section is split into two parts, related to the first two sections of the survey that was sent to stakeholders. Section 4.2 reports responses to questions relating to opinions on climate change and energy security in India. Section 4.3 refers to the second half of the survey that focused primarily on CCS technology and issues related to its development and deployment in India.

⁹ Tier 1 stakeholders are those who directly work on energy/environmental issues in India, and who would be affected by/or could influence any developments of CCS technology in India.

¹⁰ Tier 2 stakeholders are those who are presently not directly involved with work on energy/environmental issues in India, but have been in the past and or/ have an interest in how CCS could develop in India as it may affect their work in the future.

4.2 Climate change and energy in India

In total, the stakeholders were asked nine questions regarding general climate change and energy security issues in India. The first three questions specifically aimed at gathering personal and perceived attitudes towards climate mitigation and energy security concerns in India. The remaining six questions were designed to see what the stakeholders think India's current energy landscape comprises of, and how they expect this to change by 2050.

4.2.1. General attitudes on climate change and energy security

The results in this section refer to the following questions, with the choices for answers in brackets:

Q1 – How concerned are you personally about climate change and energy security in India? (*I am very concerned/moderately concerned/neutral/not concerned/not concerned at all*)

Q2 – In your opinion, what is the level of priority given to climate change mitigation and energy security by the Indian Government? (*The Indian Government gives climate change mitigation and energy security very high priority/high priority/medium priority/low priority/very low priority/I don't know*)

Q3 – What proportion of private sector companies in India takes climate change mitigation and energy security seriously? (*No companies/a small number of companies/a moderate number of companies/the majority of companies/I don't know if any companies take climate change mitigation and energy security seriously*)

On the whole, personal concerns about climate change and energy security in India were quite high. Thirteen out of the 18 respondents were 'very concerned' about climate change, and fourteen out of the 18 were 'very concerned' about energy security. Some respondents commented that these two challenges needed to be addressed collectively because of India's increasing energy demand for development and that the impacts of climate change would largely affect the poor. A few were moderately concerned about climate change in comparison to energy security, commenting that "energy security is extremely essential for sustained economic growth and poverty alleviation," and that climate change was an issue that would gain equal importance at a later stage in India. One respondent was of the opinion that "the energy policy and development of India will have a significant impact on global climate."

In terms of the level of priority given to climate change mitigation and energy security by the Indian Government, there were more varied responses between the different options. The majority of respondents thought that climate change mitigation was given a 'medium' to 'high' level of priority. In comparison, the majority thought that energy security was given a 'high' to 'very high' level of priority by the Indian Government. One comment was, "energy security has been on the top of the agenda for quite some time now, whereas climate change mitigation has started to pick up recently."

In regards to the proportion of private sector companies in India that take climate change mitigation and energy security seriously, stakeholders gave a range of responses. The greater part of responses considered that a ‘small’ to ‘moderate’ number of companies took climate change mitigation and energy security seriously. Respondents commented that the motivation to undertake any mitigation measure was primarily business driven for survival and growth, and therefore likely to be less of a concern at present to the private sector. It was noted, however, that the Clean Development Mechanism (CDM) had been “quite instrumental in spreading more information about climate change mitigation in India.” Nevertheless, one stakeholder commented that from what they had observed in the Indian business and academic communities, climate change was generally regarded as the “environmental fad of the decade, instead of a serious problem.” They thought that there was still “an acute lack of awareness” outside a very small group of people in Delhi and other metropolises in India. It was commented further that “individual companies view energy security from their own short-term perspective rather than the wider context of [the] long-term future of generations to come.”

4.2.2 India’s energy landscape

Q4 – In your opinion, which sectors currently contribute the most to India’s total carbon dioxide emissions and how might this change? Please identify the three most important sectors and rank them in the order in which you think they contribute to carbon dioxide emissions (where 1 is ‘highest contribution’). (Transport, Agriculture, Commerce & Industry, Power (electricity generation), Defence, Other, I don’t know)

Rank	Now	2030	2050
1	Power	Power	Transport
2	Transport	Commerce & Industry	Commerce & Industry, Power
3	Commerce & Industry	Transport	Agriculture

The sectors respondents identified as the current most significant contributors to climate change were ‘power,’ ‘transport,’ and ‘commerce & industry,’ where a clear majority (16/18) ranked the power sector at the top, transport second and the commerce and industry sector at third. By 2030, most respondents still ranked the power sector as the top contributor, but commerce and industry moved to second and transport was ranked at third. It was noted that India was “in need of infrastructure and that this was going to be the development objective for the next couple of decades.” In addition, it was thought that after thermal power plants, the steel sector in particular was most carbon intense.

The greater part of the responses expected the transport sector to eventually become the top contributor to India’s carbon emissions by 2050, and that power, commerce and industry would be jointly ranked as second. By 2050, the majority thought that the agriculture sector would have the third highest contribution to India’s overall carbon emissions. This is a slightly unexpected result if only CO₂ emissions

are considered, but is similar to conclusions of studies that consider all greenhouse gases. For example, the UK Committee on Climate Change (2008) showed that as CO₂ emissions reduce, emissions of non-CO₂ greenhouse gases become more significant in the bigger picture. These non-CO₂ contributors to the greenhouse gas emissions are typically difficult to reduce below a certain level, partly since they are associated with food production and are difficult to avoid.

One stakeholder commented further on each of the top three sectors considered to contribute highly to India's carbon emissions:

- *Power*: "40% of [the] population still do not have access to electricity; therefore, power generation, [transmission and distribution], and rural electrification will remain the priority area."
- *Transport*: "Focus is now being given on sustainable transportation in urban metros, [e.g. the Delhi Metro project], though, second tier cities at state level are the main guzzlers for vehicle emissions, as they are mostly very old vehicles with old technologies. The policy and support infrastructure for clean vehicles for use in urban areas is not there mainly because of the petrol lobbies."
- *Commerce & Industry (C&I)*: "SWM [(solid waste management)] is still the priority area amongst the C&I group. SWM projects are mainly public-private-partnership projects. The major barrier is credibility, governance and financial health of the municipal corporations, and owners of landfill sites. The success of the projects and private sector participation depends greatly on these factors. Other sectors within this group are the mining and metal industry, where issues mainly pertain to the technology availability."

Q5 – In your opinion, what energy resources are most important to meet the energy demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India's energy supply mix (where 1 is 'most significant contribution'). (Oil, Gas, Coal, Traditional Biomass, Other Biomass, Hydro, Renewables, Nuclear, Other, I don't know)

Rank	Now	2030	2050
1	Coal	Coal	Coal
2	Oil	Oil & Gas	Oil & Gas
3	Gas	Hydro & Renewables	Renewables

Coal was ranked outright as the main energy resource to meet India's energy demand at present, and it is expected to remain the primary choice of fuel to meet energy demand through to 2050. The majority also considered oil and gas to be an important part of the current energy resource mix, ranking them second and third, respectively. By 2030, oil and gas were jointly ranked at second, and hydropower and renewables collectively formed the 3rd most important resource expected to be used to meet energy demand. By 2050, it was expected that renewables such as wind and solar would become more prominent than hydro and form the third most important energy resource for India. Though most stakeholders saw a shift in favour of renewable sources of energy, it was noted that this would hinge upon whether the

cost of renewables-based electricity could be “drastically brought down through technology break-throughs, international cooperation, and high volume production of renewable based generation technologies.” Another comment made in terms of energy resources was that “water availability for irrigation would become a barrier for the development of the bio-fuel industry”, and that land acquisition for the renewable sector could become an issue in the future.

Q6 – In your opinion, what energy resources are most important to meet the electricity demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India’s electricity supply mix (where 1 is ‘most significant contribution’). (Oil, Gas, Coal, Traditional Biomass, Other Biomass, Hydro, Renewables, Nuclear, Other, I don’t know)

Rank	Now	2030	2050
1	Coal	Coal	Coal
2	Hydro	Hydro	Nuclear
3	Nuclear	Nuclear	Hydro & Renewables

Coal was again ranked as the most important resource through to 2050 for meeting India’s electricity demand. Hydropower was ranked as the second most important resource for electricity at present and through to 2030. By 2050, it is expected to drop to third position as part of a renewables mix that includes solar and wind. Responses consistently featured nuclear in the electricity mix, where the majority see it as the third most important resource at present and through to 2030. By 2050 nuclear is envisioned to become second to coal in terms of electricity generation. It was noted that certain technologies such as hydro and nuclear had yet to be developed for their full potential, but until then, “coal is king.”

Q7 – In your opinion, what are the main energy security concerns for India now and how might this change in the future? Please identify the three most important concerns and rank them (where 1 is ‘highest level of concern for India’). (Lack of diversity in sources of energy supply, Limited or no access to electricity for large rural population, Inadequate energy infrastructure, Highly dependent on imported oil, Highly dependent on imported gas, Highly dependent on imported coal, Highly dependent on traditional biomass, Other, I don’t know)

Rank	Now	2030	2050
1	Limited/no access for rural population	Dependence on imported oil, gas & coal	Dependence on imported oil, gas & coal
2	Dependence on imported oil	Inadequate energy infrastructure	Inadequate energy infrastructure
3	Inadequate energy infrastructure	Limited/no access for rural population	Limited/no access for rural population

When asked to consider India’s main energy security concerns, the greater part of respondents thought that the ‘limited or no access to electricity for the large rural population’ was of primary concern at present, with ‘dependence on imported oil’ and ‘inadequate energy infrastructure’ as second and third, respectively. By 2030 and

through to 2050, respondents expected that dependence on imported oil and other fossil fuels such as coal and gas will become the main concern, with inadequate energy infrastructure ranked second. During this period it is envisioned that the lack of power to the rural poor will still be an issue, with respondents ranking it as the third most important energy security concern.

One respondent was of the opinion that energy security could be handled through the market, except in situations of national distress, such as war. Otherwise, they thought, “for most circumstances, the ability to buy energy provides enough security.” Furthermore, it was thought that “practically all available energy sources are used in India” and that if there was a diversity issue in supply then it was due to “the disproportionate mix of energy sources.” Others mentioned that due to India’s huge energy demand, which is increasing further from the rise in population, it was important to consider both centralised and decentralised energy systems. Though, it was commented further that the complexity of managing highly diversified, decentralized electricity and energy systems could become a major energy security concern in the future.

Q8 – If India is planning to invest in a low-carbon and energy secure future, then which technologies should be given investment priority for development by the Indian Government and how might this change in the future? Please identify the three most important technologies and rank them (where 1 is ‘likely to be given highest priority’). (Wind Energy, Solar, Marine Energy, Hydro, Nuclear, CCS, Geothermal, Microgeneration, Other, I don’t know)

Rank	Now	2030	2050
1	Nuclear & Hydro	Solar	Solar & Nuclear
2	Wind	Nuclear	Hydro
3	Solar	CCS & Hydro	CCS

For the current Indian Government, nuclear and hydro were equally considered as the current top investment priority for India, with wind and solar as second and third, respectively. By 2030, the majority ranked outright solar as the main investment priority, with nuclear second, and CCS and hydro equally at third. By 2050, stakeholders ranked nuclear and solar equally as the top investment priority for the Indian Government, with hydro ranked second and CCS third. One respondent was of the opinion that “alternate renewable technologies are still in a nascent development stage, and the scene will change if R&D models improve or transfer of technology is undertaken.” It was also noted that “CCS will remain at the end of the technology spectrum, as it reduces the energy efficiency of the plant, in an already energy deficit country.” A few respondents mentioned bio-methanation¹¹ as a low carbon technology that may gain importance in the coming decades. However, it was

¹¹ Biomethanation or ‘methanogenesis’ is the processes where methane is generated from organic materials as they decay (using microbes called methanogens). Sources include landfills, wastewater treatment systems or in an agricultural setting where manure can be collected and treated with anaerobic digesters.

also added that “India may have advanced on many fronts, but seldom at the behest of pioneering new technologies.”

Q9 – If India is planning to invest in a low-carbon and energy secure future, then which technologies will be given investment priority for development by private sector industry in India and how might this change in the future? Please identify the three most important technologies and rank them (where 1 is ‘likely to be given highest priority’). (Wind Energy, Solar, Marine Energy, Hydro, Nuclear, CCS, Geothermal, Microgeneration, Other, I don’t know)

Rank	Now	2030	2050
1	Solar & Wind	Solar & CCS	CCS
2	Hydro	Wind & Hydro	Solar
3	Microgen	Microgen	Nuclear

Stakeholders considered solar and wind to be equally most important, hydro as second and microgen as third for current investment by private sector industry in India. By 2030, CCS was thought to be as important as solar in terms of investment priority. Wind and hydro were ranked second and microgen as third. By 2050, CCS was ranked outright as the top investment priority for private industry, with solar and nuclear as second and third, respectively. It is important to note here that roughly half the respondents answered ‘don’t know’ for the 2050 option, a few commenting that it was too difficult to gauge at this point what direction the private industry would take in the future. One comment made was that “the private sector (non-PSU companies) will play a much smaller role in low carbon technologies than the Government and PSUs¹².”

4.2.3. Further comments on climate change and energy in India

A few additional comments were made on India’s energy sector as a whole and the country’s approach to climate change mitigation:

- “The heavy industry sector is very dependent on coal and gas base thermal power plants. Their approach of climate change mitigation at present is by supplementing a small fraction of renewable energy sources at remote suitable sites. The abatement by capturing is not very high on the agenda at present despite conferences and debates at national and international level.”
- “Private Sector Participation (PSP) in low carbon technologies will depend on the incentive scheme, policies framed for the shift in technologies, coordinated working amongst various regulatory authorities/agencies along with the infrastructure to support it. While there are regulations in place for open access, in reality these are not available. In the case of wind, the transmission and distribution network is inefficient, transmission lines are supposed to be provided by the private sector, an additional cost to industry!!

¹² PSU stands for Public Sector Undertakings. This is a term commonly used in India for a government-owned corporation (company in the public sector). The term is used to refer to companies in which the government (union, state, territorial or both) owns a majority (51%) of the company equity.

In the case of the hydropower plant, land acquisition and R&R¹³ issues delay the projects. From conception to commissioning, it can take nearly 3-5 years, which delays the overall energy availability. Other alternative technologies – tidal, geothermal, etc. only have pilot projects of 1MW or so, which does not make them feasible for PSP.”

- “I consider that CCS will eventually become important for India, but not until the technology has been developed and demonstrated in the US, Europe and China. Biomass will continue to play an important role in energy as a whole. Careful societal and economic assessment of potential energy sources and climate change mitigation is required. There is still a debate to be had on whether large centralised energy system is right for India.”
- “At present, in terms of installed capacity, India has about 25% hydro, which is non-emitting source. The PM’s Council on Climate Change released the NAPCC¹⁴, which has stipulated a 5% target for green electricity in the grid by 2009-10 with 1% annual increase up to 2020. Other things remaining proportionate, India will have 40% green electricity by 2020. Even if expansion of coal takes place, electricity conservation will offset the emissions growth. India is not under Kyoto obligation to cap emissions, yet it is on course to have 40% clean electricity by 2020. Yet there is a lot of propaganda in the western press, clubbing India with China about growth of emission. Most developed countries have failed to achieve their Kyoto targets; the US has not even ratified the Kyoto treaty. To expect anything more from India is unjust.”
- “I tend to agree with the slightly confrontational attitude the Indian climate change negotiating team is taking right now, because the access and poverty agenda should not be forgotten. For India, provision of energy services is and should be the first priority till complete access and \$7500/pa/per capita¹⁵ is achieved.”
- “Unless there are transfer payments¹⁶ made to make up for the lack of access, the climate change strategy of the country should stay as it is right now.”

4.3 CCS in India

This section of the survey asked five questions in total, specifically on CCS technology and whether it may have a role to play in India. The questions also consider more detailed issues around how CCS could be deployed in India, if it is decided that it is a suitable technology to be used in the Indian context. Results are given after each question with choices for answers in brackets, where relevant.

Q10 – A number of different people and organisations talk and write about carbon capture and storage (CCS), but they don’t always have a common

¹³ Rules & Regulations

¹⁴ National Action Plan on Climate Change, 30 June 2008.

¹⁵ This is one income that can be used by some analysts to indicate a sufficient income for an individual to be deemed to be above the poverty line.

¹⁶ ‘Transfer payments’ refer to transfer of resources without any commodity in return – essentially grant money.

understanding of what CCS is. Please could you explain what you think CCS technology includes?

Since the stakeholders responding to the survey were predominantly academic researchers, technical experts and policy analysts that were directly involved with the energy sector, responses to this question were very similar. In all, the responses seemed to indicate that the respondents were quite familiar with the CCS paradigm, with answers including:

- “Technologies to de-carbonise fossil fuel combustion/gasification. A process by which CO₂ from the combustion of fossil fuels is prevented from being released into the atmosphere by being “captured”. The CO₂ is then pipeline transported, and stored/sequestered, using geological storage/conversion processes.”
- “It includes capture of carbon dioxide from the flue gases generated due to combustion of carbonaceous fuel, and capture of CO₂ generated during production syngas or producer gas or water gas. The captured CO₂ is separated from capturing media to obtain pure CO₂. The pure CO₂ is transported in supercritical state to the identified geological site for storage.”
- “As per my understanding CCS should include separation of CO₂ from source emissions in purest possible concentration using adsorptive or membrane separations and subsequently to be sequestered for permanent storage. Alternatively, if close loop is to be followed then CO₂ should be used for its valorisation to produce hydrocarbon fuels.”
- “As the name suggests, CCS includes capture, storage and transportation of captured CO₂ to sinks – geological seams, oceans. Capturing is most capital intensive in a CCS project followed by transportation via pipeline or ships. While post-combustion technology in a power and O&G¹⁷ sector is more common – a mature technology market, it is economically feasible in cluster of industries to reduce the costs. Pre-combustion technology is more common in emerging technology market, while oxyfuel is in early development phase.”

Q11 – Please read the following statements and indicate whether you agree, disagree, or have no opinion of them:

Q11.1. “The existing financial mechanisms (e.g. CDM, Carbon Markets etc.) are insufficient to support and promote clean energy solutions.” (I agree/disagree/have no opinion)

The majority of stakeholders (thirteen out of eighteen) agreed with the statement above, three respondents disagreed, and two had no opinion. In the context of the CDM and carbon markets, it was commented that “there is very little support and incentives for CDM for SME’s [small and medium enterprises] in developing countries such as India.” One respondent commented further: “I agree with the view of some of the technocrats in India that CDM and carbon markets of the future will not give enough support to CCS, for which investment is much higher than other low

¹⁷ Oil & Gas sector.

carbon technologies.” Another respondent concurred: “In my opinion, policy changes that allow CCS to be part of the CDM will be insufficient due to the energy penalty of the technology.”

Q11.2. “The international community is not doing enough to create a suitable framework for facilitating technology transfer.” (I agree/disagree/have no opinion)

The greater part of respondents (fourteen out of eighteen) agreed with the statement above, one person disagreed, and the remaining three had no opinion. Several additional comments were made regarding the issue of technology transfer including:

- “The Doha declaration on Environmental Goods and Services needs to be brought in line with carbon capture technologies to reduce the trade barriers, so that transfer of technology can penetrate at a faster pace.”
- “There has been very limited financing and technology transfer from developed to developing countries. Also the technologies being given are not necessarily those which developing countries are currently comfortable with at the moment.”
- “Technology transfer is a difficult issue due to the corporate structure of many energy companies and equipment suppliers, especially when met by large nationalised companies.”

Interestingly, one stakeholder observed that in the past, organisations such as the World Bank had imposed certain prerequisites before granting loans. One example given was the precondition to open up the Indian power market to international equipment suppliers and implementing technologies that, in some cases, were not suitable to Indian coal. Furthermore, the overall process of technology transfer was met with some scepticism; it was considered to “just mean being directed to a private company, which in turn charges large amounts as fees to share the knowledge of the technology.”

Q11.3. “The international community is not doing enough to promote technology research & development.” (I agree/disagree/have no opinion)

There was a more varied response to this statement, with half of the respondents in agreement, six out of the eighteen disagreeing, and the remaining three having no opinion. It was noted that “R&D is universal, so that seems to be going ok, it’s the transfer part that is the issue, as is nationally appropriate energy research.” One stakeholder was of the opinion that activities are in place, but more effort is needed to involve India more in fundamental research and technology development. It was commented further that the “development of solutions required have to to be more specific/designed for India – the technology needs to be appropriate.”

Q12 – Imagine that developed countries have demonstrated the full CCS chain to be safe, secure and functional at a large scale. If India were willing to try out the technology in some initial projects and then decides that wider deployment would be appropriate, then who should be responsible for covering costs and providing training for the following aspects? Aspects: (a) training for initial

projects; (b) financing for initial projects; (c) training for wider deployment; (d) finance for wider deployment. (The three most important groups that should make a contribution are developed country governments/developed country private sector/developed country public/Indian Government/Indian private sector/Indian public/other)

Rank	Training for initial projects	Finance for initial projects	Training for deployment	Finance for deployment
1	Developed country governments	Developed country governments	Developed country private industry	Developed country governments
2	Developed country private industry	Developed country private industry	Developed country governments	Indian Government & private sector
3	Indian Government	Indian private sector	Indian Government	Developed country private industry

- (a) *Training for initial projects*: the greater part of the respondents thought that the developed country governments should pay for the training for initial projects. The developed country private sector and the Indian Government were ranked second and third, respectively.
- (b) *Financing for initial projects*: the majority of respondents thought that governments of developed countries should also provide financing for initial projects. The developed country private sector and the Indian private sector were considered as the second and third most important groups that should make a contribution.
- (c) *Training for wider deployment*: it was thought by most that responsibility for covering costs for training for wider deployment should be carried out by the private sector industry from developed countries foremost. In addition, governments from developed countries and India were thought to be equally important after the private sector, in terms of training.
- (d) *Financing for wider deployment*: developed country governments were ranked first in regards to covering the costs for wider deployment. The Indian private sector industries along with the Indian Government were thought to be equally the second most important group responsible for financing projects. The private sector from developed nations was ranked third.

Additional comments made in regards to the costs for training and financing projects, both at the initial stage and for wider deployment included:

- “I do believe that the per capita argument that India has is a strong one, and I would say that the developed world, because of the cumulative emissions, has the responsibility to finance and train for initial projects and for wider deployment.”
- “A general model of education followed by handing over responsibility and cost to the Indian Government and private sector, once the technology has been proven for deployment in India and technology/cost risks minimised.”

- “This is all subject to clarity in EHS (environment, health & safety) integrity issues, IPR¹⁸, Liability issues, regulatory requirements etc.”
- A suggestion that consideration should be given to setting up local knowledge/training centres that would be sponsored by the private sector industry from developed countries.

One stakeholder commented that this question was “rather tricky, just because the differentiation between governments, public and private sector is hazy and taxation can unite those three. It was questioned that “the idea of transfer payments is always politically unpalatable, but is there a different way of doing CCS?” In addition, it should be noted that several respondents thought that there should have been another separate option as ‘International Finance Institutions’ such as the World Bank, International Monetary Fund, and the Asian Development Bank. It seems likely that if this category had been available then it would have appeared in the ranking of organisations that have a role in financing CCS projects.

Q13 – In your opinion, what are the most important actions that should be taken by developed countries (such as the UK, USA etc.) to support the development and deployment of low-carbon technology in India, including CCS if it is decided that it is a suitable technology to be used in the Indian context?

This was an open-ended question, which gathered a variety of responses. Suggestions were made to support development by “facilitating vendor to vendor transfer of technology for components and/or CCS,” and creating India as a low-cost manufacturing hub, “as India does not have sufficient geological seams for storage, power plants are scattered and pipeline transfer could be costly.” Further comments made in regards to CCS development were that the focus should be on “global R&D”, whereby facilitating frameworks for setting up a carbon price, technical and institutional capacity building, assuring technology transfer and financial aid are all very important factors.

One stakeholder was of the opinion that CCS demonstration plants should be built and operated as soon as possible in developed countries, followed by funding for a demonstration plant in India. This would require the development of international industrial and academic research collaboration to develop and deploy low carbon technologies. They added that “it is critical that whatever technologies are developed and deployed, they must be appropriate for India (in terms of geography, society, development)” and that in order to achieve this “full engagement and collaboration is required” whereby “India gets (part) ownership of the technologies.” Other opinions expressed for this question are as follows:

- “India has technical strengths: e.g. EV – REVA¹⁹; Spacecraft – Chandrayaan²⁰: which are examples of low cost technology development and

¹⁸ Intellectual Property Rights

¹⁹ India’s first electric vehicle: <http://www.revaindia.com/>

²⁰ Chandrayaan-1 is India’s first mission to the Moon launched by India’s national space agency the Indian Space Research Organisation (ISRO): <http://www.isro.org/pslv-c11/photos/index.htm>

transfer. These strengths should be used so that penetration of CCS installations across the globe increases.”

- “Share the results from the project sites. Also, they should cover the costs associated with it, as the priority of any developing country will be to provide electricity to its population through its locally available resources, if developed countries are not providing other options.”
- “(1) Demonstrate the CCS technology at a suitable scale (1000 MW coal plants) for at least 25 power plants. (2) Monitor the performance of these sites for at least 20 years.”
- “Technology development in India should be promoted with possible IPR with Indian Government or public sector so as to make technology available at affordable costs. Further, some of the technologies from developed countries may not be applicable in India due to varied scale of operation and difference in basic production technologies used at industries.”
- “The most important action is to tell the truth, the whole truth and nothing but the truth about CCS and all its implications both to Govt. of India and to the wider Indian public. No attempt should be made to arm-twist or otherwise influence [the Government of India] in to accepting CCS technology.”
- “The developed nations will first need to show that they are using CCS on their own grounds otherwise political acceptance of technology will be an uphill task and long winded.”
- “Provide access to the 440million without access, so they can get on the first rung of the ladder of development. Once the country is fairly prosperous, climate change will become a priority itself.”

Q14 – In your opinion, what are the most significant challenges to implementing CCS technology in India? Please identify and rank the three challenges that you think are most important in the context of initial projects and for widespread deployment. (The top three challenges to implementing CCS are technology readiness/construction costs/running costs/availability of skilled people/safety of carbon dioxide capture process/safety of carbon dioxide transport/safety of geological storage of carbon dioxide/public acceptability/politically acceptability/financing mechanisms (e.g. loans, CDM etc.)/water supply/inadequate geological storage capacity/high-ash content in Indian coal/other/I don’t know)

Rank	Initial projects	Widespread deployment
1	Technology readiness	Technology readiness
2	Construction & running costs	Inadequate geological storage capacity
3	Political acceptability	Construction & running costs
4	Financing mechanisms	Political acceptability
5	Safety of geological storage	Safety of geological storage

Most respondents ranked at least five to eight challenges in response to this question, although only three were asked for, and the ‘top five challenges’ are, therefore, reported here based on the rankings given by the respondents. It is also important to note that some of the respondents thought that these options were not mutually exclusive. For example, as technology develops changes in costs can be

expected. This indicates that any actions taken to address challenges to CCS must consider a relatively complex web of interrelated issues if they are to successfully support demonstration and/or deployment.

General comments made on implementing CCS projects gave the impression that the concept of CCS is far from established as an option for deployment in India - bringing it forward first at the government policy level, then at the public level, or possibly both together. 'Technology readiness' was regarded as the main challenge in terms of initial projects and widespread deployment, where the general feeling was that CCS had to be technologically demonstrated in developed countries before it could be applied to India. In terms of 'technology readiness' in particular, it was generally thought that trying out CCS with low efficiency plants would reduce their overall efficiency even further.

One stakeholder was of the opinion that "due to the age of the plants in India, their efficiency is about 35% and therefore not suitable for CCS, as 40% is recommended as a good figure for installing capture capability." Although this is a common concern, in both the developing and developed world, it should be noted that if a decision to install CCS technology has been made then the costs of the project in terms of \$/tCO₂ cost and lost output in terms of MW should be independent of base plant efficiency since the energy penalty, in terms of % point change, does not depend on base plant efficiency (Chalmers et al. 2009). Of course, the total capital cost for an individual CCS project with the same electrical output would be expected to be higher for less efficient plants, but the benefit for this cost is that more CO₂ is captured.

A few stakeholders thought it would be particularly interesting to see how CCS would cope with the high ash content of Indian coal, or whether it required to be based on imported coal. It was emphasized that "due to the characteristics of Indian coal, the technologies being developed in the West, such as IGCC, might not be a viable option for India [due to the loss of efficiency by using high-ash coal], but post-combustion capture might be a good option." There was the general view that if India were to come closer to adopting the technology, then research specific to Indian coal conditions was needed.

Furthermore, stakeholders viewed the technology in its current state to be too expensive, not only in construction but also in terms of running costs. Possible repercussions highlighted included "additional fossil fuel emissions, auxiliary power consumption, deterioration in efficiency of the generation and the cost involved in supplementing the generation due to the loss of efficiency." In addition, a comment was made on the concept of 'capture-readiness': "Building a power plant that is 'capture-ready' makes it less efficient by 1.5-2% because of turbine design, which has to allow for the secondary stream of steam for the capture facility. Cumulatively, these losses could be substantial since the losses will have to be borne until the capture facility is in place (which could take ten years or more), and there is no certainty that the plant will be fitted with the capture facility in the future." It should be noted that although some approaches to capture-readiness could involve up-front penalties such as this, it is also expected that designs which avoid significant

penalties before CO₂ capture is installed are possible, as discussed in section 2.2 and by Lucquiaud and Gibbins (2009).

Finally, it is interesting to note that stakeholders from different sectors within industry had varying viewpoints on the potential for implementing CCS technology. For example, it was commented: “Private power generators such as Reliance have little incentive to be involved in CCS since they have no influence over pricing of electricity. The central and state governments decide the tariff structure for electricity. This implies that the private players have no way of increasing the tariff, especially if they implement CCS and pass on the cost to the consumer.” In contrast, it was noted that the petroleum industry is more likely to have an interest in CCS due to the incentive of EOR, citing examples such as ONGC’s Ankaleshwar/Hazira project and the MoU signed with StatoilHydro in 2008²¹. However, since then the StatoilHydro deal has reached a stalemate due to disagreements on the way the project was heading²².

Overall comments on CCS technology varied in sentiment and included:

- “CCS is required to bridge the gap between low carbon technology and current energy demand, it is essential for developed countries to demonstrate the technology first and further fund the thermal power stations in India and China for CCS.”
- “In our reading, [CCS is] an unproven technology with unknown costs, unknown environmental implications and unknown energy implications of transportation of CO₂, hence we don’t favour it. However carbon storage in forests, in soil carbon (sustainable agriculture) and recycling of carbon into both of the above are the scientifically correct lines to be pursued for the future and we support them.”
- “India will benefit from CCS due to high proportion of power generated by fossil fuel, unit cost of power from coal based plants is among the lowest in the world. Heavy industry sector companies generally have their own coal mines for their captive production and usage of electricity. This sector is expected to expand by 4 to 5 folds by 2020 with “heavy carbon footprints”. CCS introduction seems very timely. An advantage of CCS is that it can be retro-fitted to the existing power plants, assuming all other aspects of technology are proven or sussed out.”
- “From the Indian point of view CCS has very limited application unless this technology is packaged with Enhanced Oil and Gas Recovery options. India is setting up a number of coast based thermal power plants and all these are going to be of ultra mega size, i.e. 4000MW and more. Fortunately, most of these locations are near oil and gas fields. These are possible locations where CCS could find an entry. In the land-based power plants, in view its high efficiency penalty CCS would make very little sense.”

²¹ See:

<http://www.statoilhydro.com/en/NewsAndMedia/News/2008/Pages/CooperationIndia.aspx>

²² See: <http://www.rediff.com/money/2008/aug/26ongc.htm>

5. Discussion and Conclusions

As noted in section 1, it can be tempting to assume that China and India have similar attitudes to responding to climate change and considering CCS within their energy mix. There are, however, some important differences between these two nations that are important to consider in determining whether CCS is suitable for either or both nations to deploy. In recent years, China has been involved in a number of projects with international partners. Chinese companies have also begun to construct their own pilot scale facilities and consider more ambitious plans for initial CCS projects.

India has had a very different approach to CCS. Although India has been engaged internationally on CCS, activities have generally been strictly limited to research projects and there has been some considerable scepticism about whether CCS is an appropriate option to consider in the Indian context. This report has, therefore, reviewed the context for considering CCS in India, explored whether CCS is a technically feasible option in the Indian subcontinent and presented results from a stakeholder survey which aimed to explore whether CCS was a suitable option to consider for India and, if so, how CCS development and deployment might occur.

5.1 Summary of key conclusions

Some key conclusions in this research report are:

- Coal is expected to continue to be “king” in India for several decades, despite increasing contributions to the energy mix from other sources;
- Survey respondents typically suggest that it is necessary for developed countries to demonstrate CCS at commercial scale before any commercial-scale CCS projects in India are considered and that developed countries should also begin widespread deployment first, if demonstrations are successful;
- The comments of respondents in this study again highlighted the need for careful consideration of technology transfer arrangements, including intellectual property rights (IPR), to take account of the needs of multiple stakeholders to find workable solutions in this area;
- They also highlighted the importance of ensuring that technology transferred in any agreements take account of what options are likely to be suitable to be adapted for local conditions, including careful consideration of the implications of the low quality of typical Indian coals;
- One respondent suggested that consideration should be given to establishing local knowledge/training centres within India;
- An immediate consideration is whether it would be appropriate to implement capture-ready designs for the Ultra Mega Power Plants (UMPPs) and other new fossil-fired power plants that are yet to be constructed in India;

- Both the availability of suitable storage sites and identifying routes for transporting captured CO₂ to storage sites require careful consideration;
- It seems likely that international collaboration could be valuable to build capacity in mapping and exploration of geological storage in India and also to identify alternative options given concerns over likely available volumes in the medium term and beyond; and
- Some concerns have been raised about the suitability of EOR projects for inclusion in the CDM due to the additional oil recovery. It is possible, however, that carefully selected EOR projects could be used to gather critical data and experience to support the development of other CO₂ storage projects, including many that do not involve increased hydrocarbon recovery.

These highlight a number of important areas where an evidence base already exists or should be developed for use by governments and others to inform their decisions on if and how CCS should be demonstrated and deployed, including in India. The remainder of this section provides an overview of the key themes emerging within this report. The responses draw on key findings from a desk-based review of the context for considering CCS in India (section 2) and technical potential for CCS deployment in India (section 3), combined with a stakeholder survey exploring views on the suitability of CCS for India and how it could be developed and deployed, if it is deemed to be appropriate for the Indian context (section 4).

5.2 The context for CCS in India: Energy security and climate change

Both public statements by Indian ministers and survey respondents suggest that coal will play a significant role in providing energy and electricity in India until 2050, at least. Some measures to significantly increase the role of renewables in India's energy mix are already in place and the survey respondents expect that renewables will play an increasingly significant role. Many respondents also expect that nuclear will play a part in electricity generation in India. The importance of microgeneration, probably including off-grid applications for rural electricity provision, as an investment option for industry now and until 2030 (at least) was also highlighted.

In 2007 the Indian Prime Minister set up a council to coordinate national strategies for adaptation and mitigation of climate change and India's first National Action Plan on Climate Change (NAPCC) was launched in June 2008. Although there is some scepticism about whether the NAPCC will be effective, the majority of survey respondents thought that climate change mitigation was given a 'medium' to 'high' level of priority by the Government of India. It is important to note that energy security (in various forms, including providing reliable access to electricity for the rural poor) is generally seen as a higher priority than action to mitigate the risk of dangerous climate change within India, with the majority of survey respondents suggesting that it is seen as a 'high' to 'very high' priority by the Indian Government. The greater part of responses considered that only a 'small' to 'moderate' number of companies took climate change mitigation and energy security seriously.

Since coal is expected to continue to be “king” in India for several decades, despite increasing contributions to the energy mix from other sources, it is no surprise that there is a lively debate about whether CCS should be deployed in India as part of a global response to concerns about the risk of dangerous climate change. Although CCS is not seen as an immediate priority for the Government of India or industry, survey respondents do expect it to become more important in the future, particularly for industry. It is important to note, however, that half of the respondents responded ‘don’t know’ to possible private industry priorities by 2050. It is, therefore, appropriate to consider whether CCS is a technically feasible option for India and, if so, if and when it should be used.

5.3 Is CCS an option that should be considered for India?

Based on the future investment priorities identified by survey respondents in this study, as well as government engagement and industry exploring CDM and EOR options (section 3.3), CCS could be considered as one of a portfolio of options that could have a role to play in India. It is important to note, however, that this is a live issue in the discourse on energy planning and climate change response in India and a broad range of views are expressed by different stakeholders, including some who are less positive about the potential for CCS to contribute to climate change mitigation, including in India. Although a broad range of tier 1 and tier 2 stakeholders were invited to participate in the survey reported in section 4, the respondents to this survey were primarily from the industry and research sectors, mainly with a science and engineering background. Further work could focus on gathering additional data from tier 2 stakeholders, who are not currently directly engaged in CCS activities but can be expected to be affected by how it develops.

One important factor in shaping views on whether CCS is an appropriate option for India is the proposed timing of any deployment of possible projects. In particular, survey respondents typically suggest that it is necessary for developed countries to demonstrate CCS at commercial scale before any commercial-scale CCS projects in India are considered and that developed countries should also begin widespread deployment first, if demonstrations are successful. Related to this, lack of mature technology is seen as the main concern for CCS being a viable option for India. Survey respondents also highlighted costs, political acceptability and proving safety of geological storage as key considerations in determining whether CCS deployment is a good approach for India. In the longer term, lack of adequate storage potential is also a concern.

Although there are some significant challenges, it seems likely that introducing CO₂ capture at Indian power plants could be technically feasible. One immediate consideration is whether it would be appropriate to implement capture-ready designs for the Ultra Mega Power Plants (UMPPs) and other new fossil-fired power plants that are yet to be constructed in India. Although some survey respondents expressed concerns about costs of and possible efficiency penalties for implementing CO₂ capture ready principles, it seems likely that some state-of-the-art approaches to implementing CO₂ capture readiness at power plants should not lead to a noticeable energy penalty and would increase capital cost by no more than 1%

of the total capital requirement (Lucquaiud and Gibbins 2008, Mott MacDonald 2008b). Retrofitting CO₂ capture to plants that have not been built capture-ready could also be possible, but various factors may increase costs compared to plants that had been constructed capture-ready, including restricted access to fit capture equipment and limits to being able to optimise plant integration between the base power plant and capture plant.

Both the availability of suitable storage sites and identifying routes for transporting captured CO₂ to storage sites require careful consideration. There is limited knowledge of Indian geology for storage but, as noted by the survey respondents, there are already concerns that in the medium to long term there will be insufficient capacity available. Previous studies have highlighted a significant gap in knowledge of India's deep saline aquifers, as well as its unmineable coal seams that may have some storage potential. In addition, further research is needed in characterising and accurately assessing storage capacity estimates for offshore sedimentary basins. A number of options could be explored to improve India's storage prospects including the development of novel storage approaches, e.g. collaborative work ongoing between the US and India on the potential for mineralization in basalt rocks, and the use of ship transport to allow Indian CO₂ to be stored in other regions with better CO₂ storage prospects.

One concept that has been discussed increasingly frequently in the UK and Europe is the potential value of identifying 'clusters' of CO₂ sources that can share a common infrastructure to access geological formations. Although general industrial use of coal has not been specifically examined within this study, it would be expected that any activities to identify clusters would consider both large industrial sites producing significant volumes of CO₂ and power plants. A number of drivers can lead to the development of a cluster, but one obvious example in India (and other countries) is the development of mine-mouth power plants to avoid the need to transport low quality coal over long distances.

5.4 If CCS is a suitable option for India, how should it be deployed – and what role for developed countries?

The survey respondents in this study suggest that any consideration of deployment of CCS in India should be within an appropriate international framework. A few respondents also gave examples of occasions where previous experience of engagement with the international community had not been entirely positive, partly since some of the conditions required by the international community as part of a deal had dictated changes that Indians did not want. Respondents, therefore, expressed concerns about potential prerequisites that could be contained within agreements for sharing intellectual property. They also highlighted the importance of ensuring that technology transferred in any agreements take account of what options are likely to be suitable to be adapted for local conditions, including careful consideration of the implications of the low quality of typical Indian coals.

Most aspects of CCS deployment will require some adaptation to local conditions for the sites being considered in any particular jurisdiction. One important

area for ensuring that technology choices are appropriate to Indian conditions is in determining which combination of base power plant and CO₂ capture technology should be considered, if it has been decided that CCS should be deployed. Although some adaptation of CO₂ capture technologies to local coals and operating conditions is likely to be necessary, it is likely that choice of base power plant technology will be more a more significant constraint for India. In particular, it seems likely that use of indigenous coal would tend to favour approaches that use pulverised coal combustion over gasification of coal for power production.

As already noted, adequate large-scale demonstration in developed countries is generally seen as a pre-requisite to CCS being considered as an option for India. It seems likely that there are various reasons for this position, including that large-scale projects in other countries should be used to resolve some of the critical uncertainties that are seen as potential 'showstoppers' for CCS projects within India. Although there is currently generally little appetite for commercial-scale use of CCS in India, some initial projects are now being developed, normally by oil and gas companies as they consider the potential for enhanced oil recovery (EOR) using CO₂. These projects may ultimately seek support within the Clean Development Mechanism, but it will be important that robust baselines are developed if CDM credits are to be issued for EOR projects, including appropriate consideration of how the CO₂ emissions of additional oil recovered in an EOR project should be offset against CO₂ emissions avoided by using CCS. Some concerns have been raised about the suitability of EOR projects for inclusion in the CDM due to the additional oil recovery. It is possible, however, that carefully selected EOR projects could be used to gather critical data and experience to support the development of other CO₂ storage projects, including many that do not involve increased hydrocarbon recovery.

Some respondents noted that one important action for developed countries to consider as they develop demonstration programmes, and continue CCS R&D activities, is how to establish appropriate methods to help with early engagement from India. For example, although the Government of India is seen as having an important role in initial CCS training and project financing, it was generally ranked lower in importance than developed country governments and industry by survey respondents. The greater part of respondents thought that developed country governments should pay for training for initial projects in developing countries, with private sector industry from developed countries also suggested to have a significant role in the longer term. One respondent suggested that consideration should be given to establishing local knowledge/training centres within India. Respondents also suggested that it was reasonable for developed country governments to finance both initial projects and wider deployment of CCS in India.

Technology transfer is often mentioned in the international discourse on action to mitigate the risk of dangerous climate change. The comments of respondents in this study again highlighted the need for careful consideration of technology transfer arrangements, including intellectual property rights (IPR), to take account of the needs of multiple stakeholders to find workable solutions in this area. As already noted, some survey respondents suggested that Indian scientists and engineers should be directly involved in R&D activities at an early stage and this

could then allow them to own part of the IPR related to CCS processes. There are no easy answers, but the importance of reaching agreement on key principles for technology transfer and knowledge sharing does now seem to be recognised by many key players. There are a number of ongoing efforts to support the development of frameworks that meet the requirements of all stakeholders. For example, the Sussex Energy Group, in collaboration with TERI, were commissioned to carry out a UK/India joint study on barriers to technology transfer, partly in support of the EU-India Initiative (Ockwell et al 2007).

In some areas, sharing know-how may be more important than identifying appropriate arrangements for sharing or licensing IPR. For example, it seems likely that international collaboration could be valuable to build capacity in mapping and exploration of geological storage in India and also to identify alternative options given concerns over likely available volumes in the medium term and beyond. Some significant progress in mapping critical regions with storage potential in China has been made within international collaborative programmes in recent years, so lessons learned from these projects might be useful to inform appropriate approaches to this potential activity for India. Some useful contributions to understanding Indian geological storage potential have already been made by geologists in developed countries, including the British Geological Survey in a high level study funded by the IEA Greenhouse Gas R&D Programme. There is significant scope for further work in this area, including with the involvement of Indian geologists, as well as in enhancing existing collaborative relationships to explore other storage options such as mineralization in basalts and developing understanding options for ship transport of CO₂ to different regions.

References

- Chalmers, H., J. Gibbins and M. Leach (2007) "Site Specific Considerations for Investments in New Coal-Fired Power Plants with CO₂ Capture" In: Proceedings of 24th Annual International Pittsburgh Coal Conference, Johannesburg, South Africa, September 2007.
- Chalmers, H., J. Gibbins and M. Lucquiaud (2009) "Retrofitting CO₂ capture to existing power plants as a fast track climate mitigation strategy" In: Proceedings of ASME 3rd International Conference on Energy Sustainability, San Francisco, USA, July 2009.
- Chikkatur, A. and A. Sagar (2009). "Carbon mitigation in the indian coal-power sector: Options and recommendations." *Energy Procedia* 1(1): 3901-3907.
- Committee on Climate Change (2008) "Building a low-carbon economy – The UK's contribution to tackling climate change." Crown Copyright. Available from: <URL: <http://www.theccc.org.uk/reports/building-a-low-carbon-economy>> [Accessed July 2009]
- Davison, J. (2007). "Performance and costs of power plants with capture and storage of CO₂." *Energy* 32(7): 1163-1176.
- de Coninck, H. (2008). "Trojan horse or horn of plenty? Reflections on allowing CCS in the CDM." *Energy Policy* 36(3): 929-936.
- de Coninck, H., J. C. Stephens, et al. (2009). "Global learning on carbon capture and storage: A call for strong international cooperation on CCS demonstration." *Energy Policy* 37(6): 2161-2165.
- DECC (2009a). "Road to Copenhagen." UK Department of Energy and Climate Change, Crown Copyright. Available from: <URL: http://www.decc.gov.uk/en/content/cms/what_we_do/change_energy/the_issue/cope_nhagen/copenhagen.aspx> [Accessed July 2009]
- DECC (2009b). "Guidance on Carbon Capture Readiness and Applications under Section 36 of the Electricity Act 1989: a consultation." UK Department of Energy and Climate Change. Crown Copyright. Available from: <URL: http://www.decc.gov.uk/en/content/cms/consultations/ccr_consultati/ccr_consultati.aspx> [Accessed July 2009]
- Dhar, Aarti (2009). "Jairam Ramesh to focus on reforming regulatory system." *The Hindu* [online], May 31 2009. Available from: <URL: <http://www.hindu.com/2009/05/31/stories/2009053160451800.htm>> [Accessed June 2009]
- Element Energy, Poyry Energy and British Geological Survey (2007). "Development of a CO₂ Transport and Storage Network in the North Sea: Report to the North Sea Basin Taskforce." UK Department for Business Enterprise and Regulatory Reform. Available from: <URL: <http://www.nsbtf.org/documents/file42476.pdf>> [Accessed July 2009]
- Gibbs, T. (2008). *Switched-on India: How can India address climate change and meet its energy needs*. London, UK, The Institute for Public Policy Research (ippr).

- GoI (2008). "National Action Plan on Climate Change." Prime Minister's Council on Climate Change, Government of India. Available at: <URL:<http://www.pewclimate.org/international/country-policies/india-climate-plan-summary/06-2008>> [Accessed Aug 2008].
- GoI (2009). "India negotiating emission targets and not UN's Framework Convention: Jairam Ramesh." Press Release June 30, 2009, Press Information Bureau, Government of India. Available at: <URL:<http://pib.nic.in/release/release.asp?relid=49499>> [Accessed June 30, 2009]
- Gupta, E., Sudarshan, A. (2009). Energy and poverty in India. India's Energy Security. L. Noronha, Sudarshan, A. Abingdon, UK, Routledge: 29-47.
- IEA (2007). World Energy Outlook 2007: China and India Insights. Paris, International Energy Agency.
- IEAGHG (2007). CO₂ Capture Ready Plants. IEAGHG R&D Programme Report 2007/4. Cheltenham, UK, International Energy Agency Greenhouse Gas R&D Programme.
- IEAGHG (2008). A Regional Assessment of the Potential for CO₂ Storage in the Indian Subcontinent. IEAGHG R&D Programme Report 2008/2. Cheltenham, UK, International Energy Agency Greenhouse Gas R&D Programme.
- IPCC (2005). Special Report on Carbon dioxide Capture and Storage. Cambridge University Press, Intergovernmental Panel on Climate Change.
- IPCC (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability (WGII). IPCC Fourth Assessment Report, Summary for Policymakers. Cambridge University Press, Intergovernmental Panel on Climate Change.
- Jordal, K., M. Anheden, J. Yan and L. Strömberg (2004) "Oxyfuel combustion for coal-fired power generation with CO₂ capture - Opportunities and challenges" In: Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies, Vancouver, Canada, September 2004.
- Kapila, R. V. and R. Stuart Haszeldine (2009). "Opportunities in India for Carbon Capture and Storage as a form of climate change mitigation." Energy Procedia 1(1): 4527-4534.
- Li, J., J. Gibbins et al. (2009). "Overviews of CCS development in China." In: Proceedings of the 8th US Annual Conference on Carbon Capture and Sequestration, Pittsburgh, USA, May 2009.
- Lucquiaud, M. and J. Gibbins (2009) "Retrofitting CO₂ capture ready fossil plants with post-combustion capture. Part 1: requirements for supercritical pulverized coal plants using solvent-based flue gas scrubbing." Proceedings of the Institution of Mechanical Engineers: Part A, Journal of Power and Energy 223(3): 213-226.
- McGrail, B. P., H. T. Schaef, A. M. Ho, Y.-J. Chien, J. J. Dooley, and C. L. Davidson (2006). "Potential for carbon dioxide sequestration in flood basalts." J. Geophys. Res. 111(B12201).
- Mott MacDonald (2008a) "British High Commission – UMPP Risk Analysis." Available from: <URL: <http://www.defra.gov.uk/environment/climatechange/internat/devcountry/pdf/umpp-risk-analysis.pdf>> [Accessed July 2008]
- Mott MacDonald (2008b) "CO₂ Capture-Ready UMPPs, India." Available from: <URL: <http://www.defra.gov.uk/environment/climatechange/internat/devcountry/pdf/co2-capture-ready.pdf>> [Accessed July 2008]

- Narain, M. (2007). Pathways to Carbon Capture and Sequestration in India: Technologies and Policies. Department of Civil and Environmental Engineering. Cambridge, MA, Boston, Massachusetts Institute of Technology (MIT). Master of Science in Civil and Environmental Engineering: 87.
- Ockwell, D., J. Watson et al. (2007) "UK–India collaboration to identify the barriers to the transfer of low carbon energy technology: Final report". UK Department for Environment, Food and Rural Affairs, Crown Copyright. Available from: <URL: <http://www.defra.gov.uk/environment/climatechange/international/devcountry/pdf/techtransfer-fullreport.pdf>> [Accessed July 2009]
- Schaef, H. T., B. P. McGrail, et al. (2009). "Basalt- CO₂-H₂O interactions and variability in carbonate mineralization rates." Energy Procedia 1(1): 4899-4906.
- Sethi, S. (2009). India's energy challenges and choices. India's Energy Security. L. Noronha, Sudarshan, A. Abingdon, UK, Routledge: 19-28.
- Shackley, S. and P. Verma (2008). "Tackling CO₂ reduction in India through use of CO₂ capture and storage (CCS): Prospects and challenges." Energy Policy 36(9): 3554-3561.
- Sharma, Sudhirendar (2008). "Missing the mountain for the snow." India Together [online], July 24 2008. Available from: <URL:<http://www.indiatogether.org/2008/jul/env-napcc.htm>> [Accessed June 2009]
- Simbeck, D., and W. Roekpooritat (2009). "Near-Term Technologies for Retrofit CO₂ Capture and Storage of Existing Coal-fired Power Plants in the United States." White Paper for the MIT Coal Retrofit Symposium, Mountain View, California, USA. SFA Pacific, Inc. Available at: <URL: <http://web.mit.edu/mitei/docs/reports/simbeck-near-term.pdf>> [Accessed July 2009]
- Singh, A. K., Mendhe, V.A and Garg, A. (2006). CO₂ sequestration potential of geological formations in India. 8th International Conference on Greenhouse Gas Control Technologies. Trondheim, Norway.
- Stern, N. (2006) The Economics of Climate Change: The Stern Review, UK, Cambridge University Press, Cabinet Office – HM Treasury.
- TERI (2006). National Energy Map for India: Technology Vision 2030. New Delhi, India, The Energy and Resources Institute.
- UNDP (2004). World Energy Assessment: Overview 2004 Update. New York, United Nations Development Programme.
- UNDP (2007/2008). Human Development Report 2007/2008 - Fighting climate change: Human solidarity in a divided world. U. N. D. Programme. New York, Palgrave Macmillan.
- UNFCCC (1992) "Text of the Convention." UNFCCC [online]. Available from: <URL: http://unfccc.int/essential_background/convention/background/items/2853.php> [Accessed July 2009]

Appendix A – China and CCS: A Brief Overview

At the 2009 US sequestration conference Li and co-authors reviewed CCS developments in China (Li et al., 2009). This Appendix summarises the main points from this paper since it provides a recent insight into CCS developments in China from the perspective of multiple, mostly Chinese, authors. For following more thorough coverage, including recent developments, of CCS in China (and elsewhere globally), the English-Chinese site www.captureready.com is a useful resource.

China has been a member of the Carbon Sequestration Leadership Forum since 2003 and the first Chinese national meeting on CCS was held at Tsinghua University in August 2005. Since late 2005/early 2006 memoranda of understanding have been in place with the UK and Europe that include CCS and Chinese researchers have been involved in a number of projects within the European Framework Programme, including the COACH project (<http://www.co2-coach.com/>) which aims to establish “broad cooperation between China and the EU in the field of CCS”. The first phase of the NZEC (Near Zero Emissions Coal, www.nzec.info) programme has also been a significant activity involving 28 partners, of which 19 are Chinese with the remainder based in the UK but including some multinational companies. The UK-China CAPPCCO project also includes a significant number of Chinese partners (6 out of 8) and is exploring methods for retrofitting CO₂ capture to existing plants, as well as building new plants ‘capture ready’. Within this project, sections of an IEA Greenhouse Gas R&D Programme report on capture-readiness published in English in 2007 (IEAGHG 2007) have been translated in to Chinese.

Chinese companies are already involved with a range of CCS projects. For example, the China Huaneng Group is part of the Futuregen Alliance to develop a state-of-the-art IGCC plant with capture in the USA. In July 2008, a 3000tCO₂/yr pilot plant began operating at the Huaneng Beijing Co-Generation Power Plant in a project that also involves the Thermal Power Research Institute (TPRI) and CSIRO from Australia. Other international ties include collaborative work with Petromin Resources from Canada on ECBM (enhanced coal bed methane) and the adaptation of guidelines for safe and effective CO₂ storage from the US to Chinese context by the World Resources Institute, Tsinghua University and Greengene. Greengene are also exploring the potential to demonstrate CCS within the second phase of their IGCC demonstration power plant (<http://greengene.com.cn>).

Li and co-authors (2009) conclude that “China views CCS as one of the promising technologies with significant potential for GHG emission reductions in the future.” They also note that although the Chinese Government has started to provide some funding for CCS R&D activities, the international community will have a critical role in determining the scope and scale of future CCS activity in China. One key issue will be funding and the authors note that private sector funding of CCS is starting to occur. They argue that CCS is reaching a crucial stage where it is becoming necessary to “commercialise and deploy key technologies as well as integrate the CCS system” and suggest that both collaboration and competition on technology development is emerging.

Appendix B – Overview of survey participants

A list of organisations that were invited to participate in the survey discussed in Section 4 is included below, with bold text indicating a stakeholder who responded. In some cases, more than one survey was sent to an individual organisation, so that a range of professionals that are typically present in a single institution due to the multidisciplinary nature of energy, were included in the sample. For example, surveys were returned by a policy/regulation analyst and a technical expert/researcher, both based at TERI. In most cases, however, there was only one respondent from each organisation.

<i>Sector</i>	<i>Organisation</i>	<i>Profession/area of work</i>
Industry	Infrastructure Development Finance Company Ltd	Technical expert
	KBR	Technical expert & business planner; oil & gas industry, energy policy, power
	Schlumberger	Technical expert & business planner; oil & gas industry
	Reliance Industries Ltd	Technical expert & business planner; energy financing
	National Thermal Power Corporation Ltd. (NTPC)	
	Shell India Ltd	
	MECON Ltd.	
	Oil & Natural Gas Corporation Ltd. (ONGC)	
	Power Finance Corporation Ltd.	
Indian Government	Ministry of Environment and Forests	Senior advisor/policy analyst
	Ministry of Coal	
	Ministry of Power	
Research	The Energy Resources Institute (TERI)	Researcher & policy analyst; renewables, energy policy
	Omar- Al-Mukthar University, Libya	Academic; energy education & research
	Integrated Research and Action for Development (IRADe)	Researcher & policy analyst; renewables, energy policy
	Heriot Watt Univeristy	Academic; energy education & research
	University of Nottingham	Academic; energy education & research
	Indian Institute of Technology, Mumbai	Researcher; renewables, energy, climate change
	National Environmental Engineering Research Institute (NEERI), Nagpur	Researcher; renewables, power
	World Institute of Sustainable Energy (WISE)	Researcher & policy analyst; renewables, energy policy
	World Resources Institute	
	Maulana Azad National Institute of Technology	

	IPCC/National GHG inventories	
	Central Mining Research Institute	
	Centre for Sustainable Technologies, Indian Institute of Science, Bangalore (CST IISc)	
NGOs	Greenpeace	Lobbyist; coal/regulation
	The Climate Group	
	Christian Aid	
	Development Alternatives	
	Climate Action Network	
	Indian Network on Ethics and Climate Change (INECC)	
	Centre for Science and Environment (CES)	
	WWF-India	
Other	World Bank	Technical expert & researcher; coal, energy policy
	Former Advisor (Coal) to the Government of India	Senior advisor/technical expert; coal/regulation
	AK Associates	Technical expert; renewable energy
	Advisory board on Energy to the Indian Government	Senior advisor/policy analyst
	UK Department for International Development (DFID)	
	Greentech Knowledge Solutions	
	UK Foreign and Commonwealth Office	
	Clarus Law Associates	
	Carbon Minus India	

Appendix C – Survey circulated to stakeholders in May 2009

Does Carbon Capture & Storage (CCS) technology have a role in India? A survey of your thoughts and opinions.

Introduction

This survey is intended to gather views about how important climate change, energy and Carbon Capture and Storage (CCS) are perceived to be in India. It has been sent to a wide range of stakeholders with different levels of experience and previous knowledge of energy and CCS in India. Please try to answer as many questions as you can. Since the purpose of this survey is to gather stakeholder views there are no right or wrong answers.

This survey is being carried out by Rudra Kapila (University of Edinburgh) with financial support from Christian Aid. It is part of a short research project to assess the relevance of CCS technology to India (and China) and the potential (or otherwise) for collaboration between the UK (and Europe) and India on this technology being carried out by Rudra and colleagues at the University of Surrey. It is intended that data collected in this survey will also be used in Rudra's PhD research (funded by the UK Energy Research Centre) which is analysing the potential role of CCS in India.

Sections I and II include a total of 14 questions that ask for your views on climate change, energy and CCS in India. Section III consists of 3 questions asking for background information to assist us in data analysis. We expect that the survey will take around 30 minutes to complete. Thank you for your time.

Please send responses to Rudra Kapila at Edinburgh University (r.v.kapila@sms.ed.ac.uk or fax to +44(0) 131 668 3184) by 14th June 2009 or as soon as possible thereafter. If you would like to receive a copy of the reports produced by this project, please provide your e-mail address on the extra sheet circulated with this survey.

Background information about University of Edinburgh, University of Surrey and Christian Aid

University of Edinburgh (Rudra Kapila)

The School of GeoSciences at the University of Edinburgh explores the factors and forces that shape our world and environments in which we live. As a leading interdisciplinary group, it aims to understand the interaction between the Earth's geology, atmosphere, oceans, biosphere and human responses and roles in this complex interplay. Rudra has a first degree in environmental geosciences and was previously based at the Oxford University Centre for the Environment.

Univeristy of Surrey (Hannah Chalmers and Matt Leach)

The Centre for Environmental Strategy at the University of Surrey is an internationally-acclaimed centre of excellence on sustainable development. It takes a multi-disciplinary approach to the analysis of sustainable systems, integrating strong, engineering-based approaches with insights from the social sciences to develop action-oriented, policy-relevant responses to long-term environmental and social issues. Hannah and Matt both have first degrees in mechanical engineering and also have close links with Imperial College London.

Christian Aid

Christian Aid is a Non-Governmental Organisation (NGO) whose primary focus is on development. For more than sixty years Christian Aid has been providing relief to those hit by disaster, helping people help themselves out of poverty and speaking out against injustice. Christian Aid works with partner organisations in a range of countries, including India, regardless of religion or nationality.

Section I: Climate Change and Energy in India

This section contains 9 questions and is intended to explore your opinions on the importance of climate change and energy security for India. It asks for your views on how energy and electricity supply in India might develop between now and 2050. After each question there is space for additional comments. Please feel free to use this as much or as little as you wish.

1. How concerned are you personally about climate change and energy security in India? Please check appropriately.

Answer Choices	Climate Change	Energy Security
Very concerned		
Moderately concerned		
Neutral		
Not concerned		
Not concerned at all		

Additional comments:

2. In your opinion, what is the level of priority given to climate change mitigation and energy security by the Indian Government? Please check appropriately.

Answer Choices	Climate Change Mitigation	Energy Security
Very high priority		
High priority		
Medium priority		
Low priority		
Very low priority		
I don't know		

Additional comments:

3. What proportion of private sector companies in India take climate change mitigation and energy security seriously? Please check appropriately.

Answer Choices	Climate Change Mitigation	Energy Security
No companies		
A small number of companies		
A moderate number of companies		
The majority of companies		
I don't know		

Additional comments:

4. In your opinion, which sectors currently contribute the most to India's total carbon dioxide emissions and how might this change? Please identify the three most important sectors and rank them in the order in which you think they contribute to carbon dioxide emissions (*where 1 is 'highest contribution'*).

Sector	Rank now	Rank in 2030	Rank in 2050
Transport			
Agriculture			
Commerce & Industry			
Power (electricity generation)			
Defence			
Other (<i>please specify</i>):			
I don't know			

Additional comments:

5. In your opinion, what energy resources are most important to meet the energy demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India's energy supply mix (*where 1 is 'most significant contribution'*).

Energy resource	Rank now	Rank in 2030	Rank in 2050
Oil			
Gas			
Coal			
Traditional Biomass			
Other Biomass (e.g. Jatropha for biofuels etc.)			
Hydro			
Renewables (e.g. Wind, Solar)			
Nuclear			
Other (<i>please specify</i>):			
I don't know			

Additional comments:

6. In your opinion, what energy resources are most important to meet the electricity demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India's electricity supply mix (where 1 is 'most significant contribution').

Energy resource	Rank now	Rank in 2030	Rank in 2050
Oil			
Gas			
Coal			
Traditional Biomass			
Other Biomass (e.g. combustion at power plants)			
Hydro			
Renewables (e.g. Wind, Solar)			
Nuclear			
Other (please specify):			
I don't know			

Additional comments:

7. In your opinion, what are the main energy security concerns for India now and how might this change in the future? Please identify the three most important concerns and rank them (where 1 is 'highest level of concern for India').

Energy security concern	Rank now	Rank in 2030	Rank in 2050
Lack of diversity in sources of energy supply			
Limited or no access to electricity for large rural population			
Inadequate energy infrastructure			
Highly dependent on imported oil			
Highly dependent on imported gas			
Highly dependent on imported coal			
Highly dependent on traditional biomass			
Other (please specify):			
I don't know			

Additional comments:

8. If India is planning to invest in a low-carbon and energy secure future, then which technologies should be given investment priority for development by the Indian Government and how might this change in the future? Please identify the three most important technologies and rank them (where 1 is 'likely to be given highest priority').

Low Carbon Technology	Rank now	Rank in 2030	Rank in 2050
Wind Energy			
Solar			
Marine Energy (e.g. Tidal, Wave)			
Hydro			
Nuclear			
CCS			
Geothermal			
Microgeneration			
Other (please specify):			
I don't know			

Additional comments:

9. If India is planning to invest in a low-carbon and energy secure future, then which technologies will be given investment priority for development by private sector industry in India and how might this change in the future? Please identify the three most important technologies and rank them (where 1 is 'likely to be given highest priority').

Low Carbon Technology	Rank now	Rank in 2030	Rank in 2050
Wind Energy			
Solar			
Marine Energy (e.g. Tidal, Wave)			
Hydro			
Nuclear			
CCS			
Geothermal			
Microgeneration			
Other (please specify):			
I don't know			

Additional comments:

[illegible]

Section II: CCS in India

Some of the questions in Section I explored whether CCS may have a role to play in India in your opinion. This section contains 5 questions and considers some more detailed issues around how CCS could be deployed in India, if it is decided that it is a suitable technology to be used in the Indian context. As in Section I, after each question there is space for additional comments. Please feel free to use this as much or as little as you wish.

10. A number of different people and organisations talk and write about carbon capture and storage (CCS), but they don't always have a common understanding of what CCS is. Please could you explain what you think CCS technology includes?

11. Please read the following statements and indicate whether you agree, disagree or have no opinion of them.

	Statement	Agree	Disagree	No Opinion
11.1	The existing financial mechanisms (e.g. CDM, Carbon Markets) are insufficient to support and promote clean energy solutions.			
11.2	The international community is not doing enough to create a suitable framework for facilitating technology transfer.			
11.3	The international community is not doing enough to promote technology research & development			

Additional comments:

Survey continues over...

One definition of CCS is that it is trapping the carbon dioxide emissions from power stations and industrial sites, then transporting it to be buried deep underground so that it does not escape into the atmosphere. Please use this definition for the remaining questions in this section.

12. Imagine that developed countries have demonstrated the full CCS chain to be safe, secure and functional at a large scale. If India were willing to try out the technology in some initial projects and then decides that wider deployment would be appropriate, then who should be responsible for covering costs and providing training? Please identify and rank the three most important groups for each aspect (A, B, C & D) that should make a contribution in your opinion (where 1 is 'most significant contribution').

	A. Training for initial projects	B. Finance for initial projects	C. Training for wider deployment	D. Finance for wider deployment
Developed country governments				
Developed country private sector				
Developed country public				
Indian Government				
Indian private sector				
Indian public				
Other (please specify):				

Additional comments:

13. In your opinion, what are the most important actions that should be taken by developed countries (such as the UK, USA etc.) to support the development and deployment of low-carbon technology in India, including CCS if it is decided that it is a suitable technology to be used in the Indian context?

14. In your opinion, what are the most significant challenges to implementing CCS technology in India? Please identify and rank the three challenges that you think are most important (where 1 is ‘most likely to prevent CCS implementation in India’).

Barriers to CCS	Rank for initial projects	Rank for widespread deployment
Technology readiness		
Construction costs		
Running costs		
Availability of skilled people		
Safety of carbon dioxide capture process		
Safety of carbon dioxide transport		
Safety of geological storage of carbon dioxide		
Public acceptability		
Political acceptability		
Financing mechanisms (e.g. loans, CDM etc.)		
Water supply		
Inadequate geological storage capacity		
High ash content in Indian coal		
Other (please specify):		
I don't know		

Additional comments:

Please feel free to make any additional comments about CCS in India here:

Section III: Background information

This section contains 3 questions in total and is intended to collect information to help us analyse any significant differences between the perspectives of different stakeholder groups who have participated in this survey.

15. Do you work in the energy field directly? (Please delete appropriately)

- a) Yes
- b) No (if no, then please skip question 16)

16. What is the main focus area of your work? (check all that apply)

- a) Oil & gas industry ☐
- b) Coal industry ☐
- c) Power industry ☐
- d) Transmission/distribution ☐
- e) Renewable energy ☐
- f) Energy Policy ☐
- g) Energy financing ☐
- h) Regulation ☐
- i) Other (please specify) _____

17. What is your profession?

- a) Policymaker ☐
- b) Regulator ☐
- c) Technical expert ☐
- d) Business planner ☐
- e) Policy analyst ☐
- f) Lobbyist/campaigner ☐
- g) Researcher ☐
- h) Other (please specify) _____

Thank you for your time in filling out this survey, your opinions and comments are very much valued and appreciated.

Data collected in this survey will be presented in a research report written by Rudra and colleagues at the University of Surrey for the Christian Aid project. It will also be used in Rudra's PhD thesis and related academic papers. The use of data will follow standard academic practice, so your identity (including company/affiliation) will not be reported although your profession and sector may be, where appropriate. No other use of the information gathered will occur without your prior written consent.